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ARMY ENVIRONMENTAL HYGIENE AGENCY ABERDEEN PROVING GR--ETC F/G 6/10  
EVALUATION OF THE POTENTIAL HAZARDS FROM ACTINIC ULTRAVIOLET RA--ETC(U)  
DEC 76 T L LYON, W J MARSHALL, D H SLINEY

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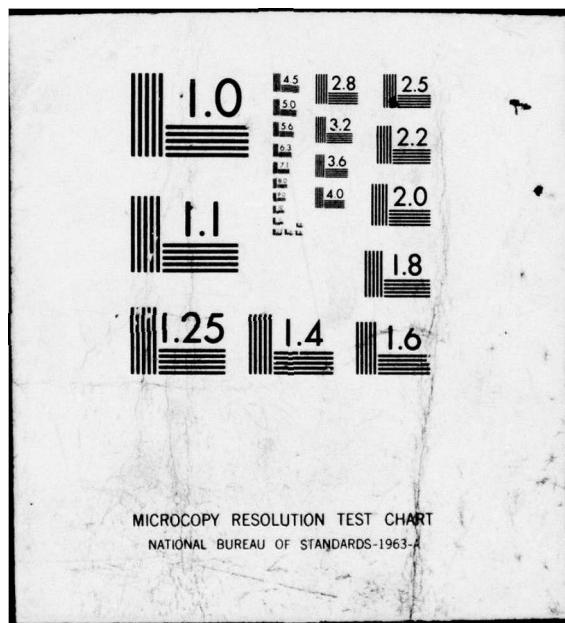
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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0053-77  
EVALUATION OF THE POTENTIAL HAZARDS FROM ACTINIC ULTRAVIOLET RADIATION  
GENERATED BY ELECTRIC WELDING AND CUTTING ARCS  
DECEMBER 1975 - SEPTEMBER 1976

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US ARMY  
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ABSTRACT

A special study of the potential hazards from actinic ultraviolet radiation generated from various welding processes was conducted by the US Army Environmental Hygiene Agency as part of a cooperative effort with the American Welding Society Committee on Safety and Health. It was determined that potentially hazardous ultraviolet radiation was emitted by all of the welding processes that were evaluated. These processes included: gas tungsten arc welding, gas metal arc welding, flux cored arc welding, plasma arc cutting, plasma arc welding and shielded metal arc welding.

It is recommended that: needless exposure be avoided; the exposure be limited to the durations given in Appendix C; the operators should wear protective equipment which absorbs the ultraviolet radiation and that welding and cutting operations should be shielded whenever possible.

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EVALUATION OF THE POTENTIAL HAZARDS FROM ACTINIC ULTRAVIOLET RADIATION  
GENERATED BY ELECTRIC WELDING AND CUTTING ARCS  
DECEMBER 1975 - SEPTEMBER 1976

1. AUTHORITY. AR 40-5, Health and Environment, 25 September 1974.
2. REFERENCES.
  - a. AR 10-5, Organization and Functions, Department of the Army, 1 April 1975.
  - b. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.
  - c. TB MED 279, Control of Hazards to Health from Laser Radiation, 30 May 1975.
  - d. TM 9-237, Operator's Manual Welding Theory and Application, 6 November 1967.
3. PURPOSE. To evaluate the potential health hazards from actinic ultraviolet radiation generated by electric welding and cutting arcs, to attempt to develop a simplified method of evaluating welding operations without the need for lengthy and costly measurements, and to make recommendations designed to limit exposure of personnel operating and in the vicinity of this equipment.
4. GENERAL.
  - a. Background. Although open welding operations are common within many Army maintenance facilities and industry, only a few previous attempts have been performed to define the optical radiation hazards generated by electric welding and cutting arcs. These processes produce substantial levels of actinic ultraviolet radiation which can cause severe "sunburn" (erythema) of the skin and welders flash (photo-keratitis) of the cornea of the eye. Chronic exposure to ultraviolet radiation over several years is widely believed to cause skin cancer. Over the past 75 years, protective methods have been developed empirically to protect the welder himself. With the increased usage of welding equipment in the past decade, exposure of welder's helpers and other personnel in the vicinity of open welding operations has increased significantly. There has been insufficient information available regarding the ultraviolet radiation emitted from welding arcs which would permit the calculation of safe exposure conditions in the vicinity of welding operations.

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b. Objective. A major objective of this study was to determine if fundamental relationships exist between arc current, arc length and radiometric and photometric quantities such as actinic ultraviolet irradiance, luminance, spectral distribution, and total irradiance for several welding processes with different work materials and shielding gases. Information on these relationships would permit the derivation of formulas for permissible exposure durations as a function of distance between the exposed individual and the arc. In this project, many uncommon arc currents and arc lengths were used simply to obtain a better physical understanding of the influence of arc parameters upon the potential hazards to skin and eyes. A secondary objective of this study was to compare the performance of less expensive ultraviolet meters with that of more sophisticated instrumentation. These comparisons are not presented in this report. Although the present study is concerned primarily with actinic ultraviolet radiation hazards for a few welding processes, future studies are planned for other processes such as carbon arc gouging and plasma spraying (PSP). Also, a separate report will deal with the potential retinal injury hazards from these sources.

c. Welding Processes Studied. Radiometric and photometric measurements of over 100 different arc welding and cutting conditions (called events in this report) were performed by personnel from the US Army Environmental Hygiene Agency (USAEEHA) at the Union Carbide Corporation facility in Florence, SC. Six processes were evaluated: gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), plasma arc cutting (PAC), plasma arc welding (PAW), and shielded metal arc welding (SMAW).

d. American Welding Society (AWS) Contribution. This cooperative effort with the Union Carbide Corporation was made possible through the coordinating efforts of the Project Committee on Radiation of the AWS Committee on Safety and Health. Dr. John A. Hogan, formerly Laboratory Division Head at Union Carbide, Mr. O. A. Ullrich, of Battelle Memorial Institute, and Mr. William B. Murray from the National Institute of Occupational Safety and Health (NIOSH) participated in the measurement program with USAEEHA personnel at Union Carbide. Prior to these measurements, Mr. Ullrich had measured the angular dependence of the irradiance to determine the optimum measurement position for the major study. Additionally, measurements of ultraviolet reflectivity of paints and welding curtain surfaces were performed at Battelle concurrently with this study as part of the Project Committees' overall effort to quantify the optical radiation hazards in welding.

e. Instrumentation. A partial list of the instrumentation used to measure the radiometric and photometric quantities follows. Data from all of the instruments have not been completely reduced.

- (1) Tektronix Model J20 Rapid - Scan Spectrometer.
- (2) EG&G Model 585 Spectroradiometer System.

- (3) Molelectron Model PR-100 Pyroelectric Radiometer.
- (4) United Detector Technology Model 40x Optometer with Radiometric and Photometric Filters.
- (5) Photo-Research Model 1980 Pritchard Photometer.
- (6) Questor Telephoto Radiometer System with Nikon-F 35mm Camera.
- (7) International Light Model IL 730 U.V. Actinic Radiometer.
- (8) CBS U.V. Hazard Monitor developed for NIOSH.
- (9) Solar Light Co., Ultraviolet Meter.
- (10) Calibrated Neutral Density Filters.
- (11) Ultraviolet Products Inc., Model J225, Ultraviolet Meter.
- (12) Photometrics, Inc., Model 200 EDP Scanning Microscope.
- (13) Varian Model F-80A X-Y Recorder.
- (14) Hewlett-Packard Model 7035B X-Y Recorder.
- (15) Calibrated Metal Plates for measuring electrode separation.

f. Measurement Techniques.

- (1) To reduce erroneous measurements from other electromagnetic radiation generated by the various arcs, these instruments were either operated from internal batteries or from a constant voltage isolation transformer. Detector cables were shielded with coaxial braid and carefully grounded to the detector and readout chassis. These shielding techniques were periodically checked by placing a nonmetallic opaque shield over the detector aperture during operation of the arc.
- (2) The instruments were calibrated against a 1000-W standard lamp for total and spectral irradiance. The calibration lamp was checked by the US Army Meteorology and Calibration Center, Redstone Arsenal, AL, which maintains intercomparisons with the National Bureau of Standards. The instruments' reading tolerances are within 10 percent. This degree of accuracy is far in excess of what was required for this study, since very slight changes in arc conditions caused measured values to fluctuate by 20 percent.

g. Radiometric and Photometric Terms and Units. Appendix A contains a table of the radiometric and photometric terms and units utilized in this report.

h. Definitions. A glossary of various terms used in welding technology and optical radiation hazard analysis is contained in Appendix B.

## 5. FINDINGS.

a. General. Radiometric measurements were made at an angle where the UV irradiance was the greatest to depict worst case exposure conditions (as reported by Mr. Ullrich to the AWS Project Committee on Radiation). Most measurement distances were either 1 m or 2 m from the source. Figures 1 and 2 depict a representative example of the equipment setup. The base metals were either flat plate, cold rolled steel or aluminum which was degreased and used as received. No significant change within the output optical radiation was noted between flat plate or fillet weld during an initial measurement test. Appendix C contains the arc parameters, the measured data and the results for the various series of events.

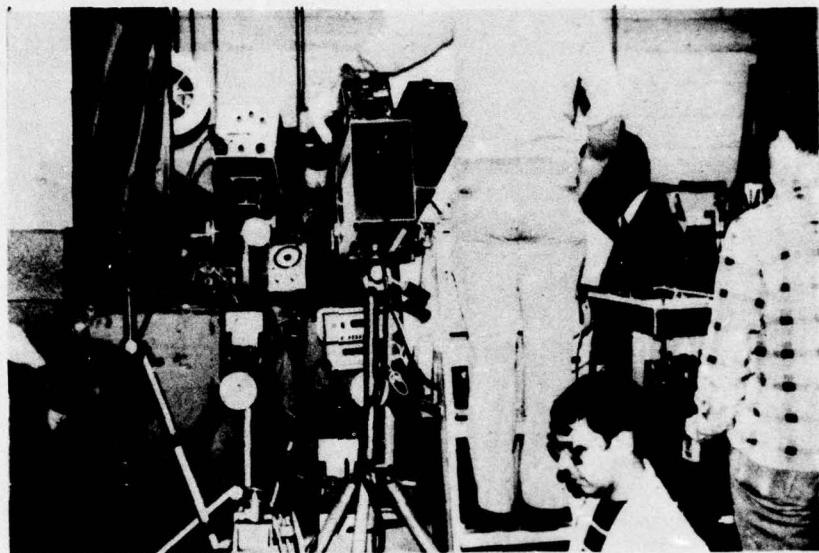
b. Spectral Distribution. The absolute spectral distribution in the ultraviolet was obtained for each type of welding or cutting process using an EG&G Spectroradiometer System. Several sample spectral distributions are contained in Appendix C.

c. Effective Actinic UV Irradiance. The effective actinic UV irradiance was computed by weighting the absolute spectral distribution measured by the EG&G Spectroradiometer System against the Army Protection Standard [identical to the Threshold Limit Value® (TLV) ] for skin and corneal exposure between 200 and 315 nm (see Table 1). Although the bandwidth of the instrument was 3 nm, the spectral weighting was made in 5 nm intervals. The CBS UV Hazard Monitor was spectrally weighted to the TLV spectral sensitivity curve and was also a primary source of data. Appendix C contains the measurement results ( $E_{UV}$ ) for each series of events at a particular measurement distance and elevation angle for the instrumentation.

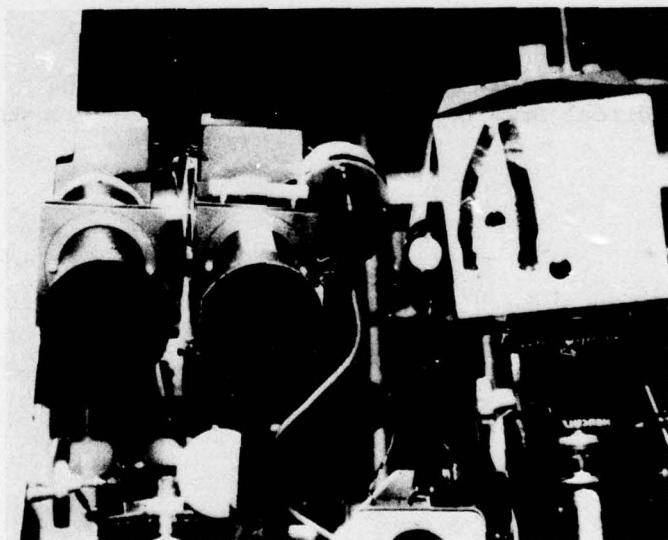
d. Irradiance Versus Distance. Measurements of the arcs were made in each case at a fixed distance or 1 m or 2 m. To be reasonably assured that the total effective ultraviolet irradiance followed the inverse-square-law within the working environment for a low-fume condition, further tests were performed at USAEHA. Rayleigh scattering increases rapidly with decreasing

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® TLV for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.

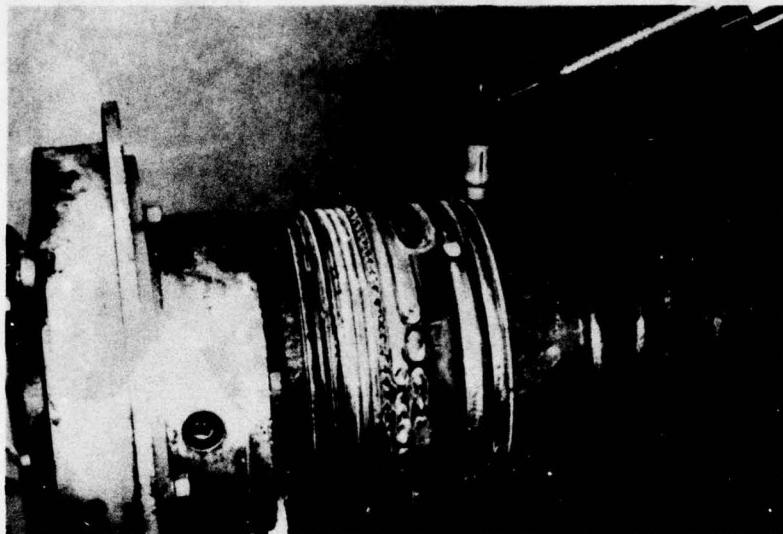


Instrumentation Readouts



Detectors were pointed at the arc at nearly the same elevation angle and distance

Figure 1. Instrumentation Layout for Measurement of GTAW and GMAW.



**Figure 2.** GTAW Welding Arrangement Using a Rotating Pipe Fixture and Cylindrical Drum to Maintain a Constant Arc Length.

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TABLE 1. ULTRAVIOLET RADIATION PROTECTION STANDARDS FROM TABLE 2-5, AR 40-46.

Wavelength (nm)	Protection Standard (mJ/cm <sup>2</sup> )	Relative Spectral Effectiveness $S_{\lambda}$
200	100	0.03
210	40	0.075
220	25	0.12
230	16	0.19
240	10	0.30
250	7.0	0.43
254	6.0	0.5
260	4.6	0.65
270	3.0	1.0
280	3.4	0.88
290	4.7	0.64
300	10	0.30
305	50	0.06
310	200	0.015
315	1000	0.003

wavelength; therefore, a monochromatic source was chosen at a wavelength shorter than the most effective actinic wavelength of 270 nm. Scattering near a low-pressure mercury lamp (254 nm) was studied photographically and the irradiance versus distance from this lamp was also measured. These tests will be conducted in the future with arcs.

(1) In normal dry laboratory conditions (low concentration of airborne particulates) the irradiance follows the inverse square law within 90 percent for distances between 50 cm and 10 m. The atmospheric attenuation coefficient  $\mu$  would typical approximately  $1-3 \times 10^{-5} \text{ cm}^{-1}$ . However, once substantial levels of ozone were generated from arc one would expect much higher initial absorption of radiation.

(2) Photographs of the lamp source taken through a 254 nm filter with a pinhole camera revealed a sharp image. Fumes would be expected to enlarge the source size. An enlarged source size would result in a further departure from the inverse-square law at locations very near the source (e.g. to 1 m).

e. Fume Generation. The generation of smoke and fumes in the vicinity of the arc greatly influences the total ultraviolet radiation levels surrounding the arc. Absorption (e.g. where  $\mu = 290 \text{ cm}^{-1}$  at 254 nm) by ozone will reduce the irradiance in all directions; whereas attenuation by scattering will tend to enlarge the effective source size and extend the near-field around the arc where the inverse-square law does not apply. Exhaust systems were used during all of the measurements in order to minimize this effect. The estimated levels of fume generation for a typical current setting for the processes of interest are provided in Table 2.

## 6. DISCUSSION.

a. Protection Standards. The protection standards for actinic UV (AR 40-46) are contained in Table 1. The protection standards vary significantly for different wavelengths between 200 nm and 315 nm. The maximum exposure level is  $3 \text{ mJ/cm}^2$  at 270 nm during an 8-hour exposure period for each 24-hour interval.

b. Permissible Exposure Duration. Appendix C also contains the actinic UV measurements weighted to 270 nm (i.e., the "effective UV irradiance") for the various processes. Assuming that the irradiance decreases with the square of the distance to the source, these figures contain the "worst-case" mathematical relationships for actinic UV irradiance versus arc current and exposure distance. Then the maximum permissible exposure duration is given by  $3 \text{ mJ/cm}^2$  divided by  $E_{UV}$ . The figures in Appendix C contain the maximum permissible exposure durations for various distances, arc currents and processes.

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TABLE 2. APPROXIMATE FUME GENERATION RATES FOR SOME WELDING PROCESSES AND ELECTRODES.

Process	Electrode	Shielding Gas	Approx. Current Amps	Polarity	Approx. Fume Generation Rate g/min.
MILD STEEL TEST PLATE					
GTAW	EWTh-2	Ar	50-300	DCSP	less than 0.2
GTAW	EWTh-2	He	50-275	DCSP	less than 0.2
GMAW	E70S-4	CO <sub>2</sub>	90-350	DCRP	0.2 - 0.4
GMAW	E70S-4	95% Ar, 5% O <sub>2</sub>	150-350	DCRP	0.2 - 0.4
FCAW	E70T-1	CO <sub>2</sub>	175-350	DCRP	0.9 - 1.3
SMAW	E6013	none	100-200	DCRP	0.8 - 1.2
SMAW	E7018	none	100-200	DCRP	0.5 - 0.7
SMAW	E7024	none	100-200	DCRP	0.3 - 0.5
ALUMINUM TEST PLATE					
GTAW	EWTh-2	Ar	50-265	AC-HF	less than 0.2
GTAW	EWTh-2	He	50-200	AC-HF	less than 0.2
GMAW	E5356	Ar	150-300	DCRP	less than 0.2
GMAW	E5356	He	125-300	DCRP	less than 0.2

c. Ultraviolet Welding Hazard Index.

(1) Because of the strong absorption of short ultraviolet (UV-C) radiation by normal air and because of further attenuation of all ultraviolet radiation by fumes, gases, and vapors created during the welding process, the effective UV irradiance may decrease more rapidly with distance than the simple "inverse-square rule." However, measurements with a mercury vapor lamp indicated that the absorption was not significant within the potentially hazardous distances from these sources. On the other hand, at locations near the arc, the irradiance will not decrease as rapidly as inverse-square with distance, since the cloud of fumes surrounding the arc tends to diffuse the radiation source. The "inverse-square rule" applies only when the measurement distance is much greater than the source size. Future investigation is required to determine the actual UV source size, for processes which generate large amounts of fumes.

(2) The ultraviolet radiation therefore decreases gradually at distances greater than 10 cm from the arc and should normally be decreasing more rapidly (due to attenuation by air) than inversely as the square of the distance at points greater than one meter. The general form for the equation for the effective irradiance  $E_{UV}$  is:

$$E_{UV} = \frac{k_1 I k_2 e^{-\mu r}}{(a+r)^2} \quad (1)$$

$k_1$  = multiplicative constant which varies with welding process

$k_2$  = exponential constant which varies with welding process (generally ranges between 1.5 and 2.5)

$\mu$  = atmospheric attenuation coefficient (varies with exhaust system and process), in  $\text{cm}^{-1}$  ( $\mu = 1$  to  $3 \times 10^{-5} \text{cm}^{-1}$  at 254 nm for clean and dry air)

$I$  = arc current in A

e = base of natural logarithms

r = distance from arc in cm

a = effective size of source (including enlargement by diffusing fumes) in cm

(3) To develop a hazard index for calculating permissible exposure durations at given locations near the arc, one is faced with the need to

greatly simplify the form of equation (1) and to combine this formula with the following formula for permissible exposure duration  $t_{max}$ :

$$t_{max} = (0.003 \text{ J/cm}^2) E_{\mu\text{v}} \quad (2)$$

(4) Therefore, the use of a hazard index value V for each process could permit the use of a simple formula for distances greater than one meter from the arc:

$$t_{max} = r^2/V \quad (3)$$

Figures of exposure duration  $t_{max}$  are provided in Appendix C for the processes studied. A table of values for the index V could be readily prepared if the inverse-square relation is adequately tested, and if future UV measurements of production welding operations confirm that the exposure durations developed in this study are indeed valid for a variety of environments.

7. CONCLUSION. Electric welding and cutting arcs emit sufficient actinic ultraviolet radiation to exceed the current protection standards to individuals located near the arc. However, these devices may be operated safely provided that the operators and bystanders are informed of the potential hazards, and permissible exposure durations, and take appropriate precautions.

8. RECOMMENDATIONS. The following recommendations apply to personnel working in the vicinity of welding arcs.

a. Avoid needless exposure of the skin and eyes to the radiation emitted by the arc (paragraph 1-4d, AR 40-46).

b. Limit the exposure duration to unprotected individuals such as bystanders, some welders helpers, and passers by as determined from Appendix C (paragraph 1-4d, AR 40-46).

c. Operators should wear full coverage clothing, face shields, and gloves which are opaque to ultraviolet radiation (paragraph 1-4d, AR 40-46).

d. Welding and cutting operations should be screened or employ other opaque structures to eliminate exposure to unprotected personnel whenever possible (paragraph 1-4d, AR 40-46).

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APPENDIX A  
ISEFIL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS<sup>1,2</sup>

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	$Q_e$	Joule (J)	Quantity of Light	$\Omega_v$	$\Omega_v = \int \phi_v dt$		Lumen-second (lx·s) (talbot)
Radiant Energy Density	$W_v$	$W_v = \frac{dQ_e}{dv}$	Joule per cubic meter ( $J \cdot m^{-3}$ )	$N_v$	$N_v = \frac{dQ_v}{dv}$		Talbot per square meter ( $m^{-2}$ )
Radiant Power (Radiant Flux)	$\Phi_e \cdot P$	$\Phi_e = \frac{d\Phi_e}{dt}$	Watt (W)	Luminous Flux	$\Phi_v$	$\Phi_v = 680 \int \frac{d\phi_v}{da} V(\lambda) da$	Lumen (lx)
Radiant Exitance	$N_o$	$N_o = \frac{d\Phi_e}{da} = \int I_o \cdot \cos \theta da$	Watt per square meter ( $W \cdot m^{-2}$ )	Luminous Exitance	$N_v$	$N_v = \frac{d\Phi_v}{da} = \int I_v \cdot \cos \theta dv$	Lumen per square meter $m^{-2}$
Irradiance or Radiant Flux Density (Irradiance Rate in Photobiology)	$E_o$	$E_o = \frac{d\Phi_e}{da}$	Watt per square meter ( $W \cdot m^{-2}$ )	Illuminance (luminous flux density)	$E_v$	$E_v = \frac{d\Phi_v}{da}$	Lumen per square meter $m^{-2}$ lux (lx)
Radiant Intensity	$I_o$	$I_o = \frac{d\Phi_e}{d\Omega}$	Watt per steradian ( $W \cdot sr^{-1}$ )	Luminous Intensity (candela power)	$I_v$	$I_v = \frac{d\Phi_v}{d\Omega}$	Lumen per steradian $m^{-2}$ or candela (cd)
Radiance	$I_o^*$	$I_o^* = \frac{d^2\Phi_e}{d\Omega \cdot da \cdot \cos \theta}$	Watt per steradian and per square meter ( $W \cdot sr^{-1} \cdot m^{-2}$ )	Luminance	$I_v^*$	$I_v^* = \frac{d^2\Phi_v}{d\Omega \cdot da \cdot \cos \theta}$	Candela per square meter ( $cd \cdot m^{-2}$ )
Radiant Exposure (Irradiance in Photobiology)	$H_o$	$H_o = \frac{d\Phi_e}{da}$	Joule per square meter ( $J \cdot m^{-2}$ )	Light Exposure	$H_v$	$H_v = \frac{d\Phi_v}{da} = \int E_v dt$	Lux-second (lx·s)
				Luminous Efficacy (of radiation)	$K$	$K = \frac{\Phi_v}{\Phi_e}$	Lumen per watt $(m^{-2} \cdot W^{-1})$
				Luminous Efficiency (of a broad band radiation)	$V(\cdot)$	$V(\cdot) = \frac{K}{K_B} = \frac{K}{680}$	Unitless
Radiant Efficiency <sup>3</sup> (of a source)	$\eta_o$	$\eta_o = \frac{P}{P_i}$	unitless	Luminous Efficacy <sup>4</sup> (of a source)	$\eta_v$	$\eta_v = \frac{\Phi_v}{P_i}$	Lumen per watt $(m^{-2} \cdot W^{-1})$
Optical Density <sup>5</sup>	$D_o$	$D_o = -\log_{10} I_o$	unitless	Optical Density <sup>6</sup>	$D_v$	$D_v = -\log_{10} I_v$	Unitless
				Retinal Illuminance in Trolands	$E_t$	$E_t = \frac{L_v}{S_D}$	Troland (td) = luminescence in $cd \cdot m^{-2}$ times pupil area in $m^{-2}$

- The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript  $\lambda$ . For example, spectral irradiance  $H_\lambda$  has units of  $W \cdot m^{-2} \cdot m^{-1}$ .
- While the **watt** is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the **m** or **um** are most commonly used to express wavelength.
- $P_i$  is electrical input power in watts.
- $\tau$  is the transmission
- At the source  $I = \frac{dI}{dn}$  and at a receptor  $I = \frac{dE}{dn}$

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APPENDIX B

GLOSSARY OF TERMS USED IN WELDING TECHNOLOGY  
AND OPTICAL RADIATION HAZARD ANALYSIS

accommodation - the ability of the eye to adjust focus for various distances

aphakia - having no lens in the eye, e.g., after cataract removal

aqueous humor - fluid in the anterior chamber of the eye

base metal (material) - the metal (material) to be welded, brazed, soldered, or cut - see also substrate

blepharitis - inflammation of the eyelids

blepharospasm - spasm of eyelid muscles

blind spot - normal defect in visual field due to position at which optic nerve enters the eye

cataract - an opacity (cloudiness) of the lens

incipient - any cataract in its early stages, or one which has sectors of opacity with clear spaces intervening

. congenital - one which originates before birth

senile - a hard opacity of the lens occurring in the aged

chorioretinitis - inflammation of the choroid and retina

choroid - vascular layer adjacent to the retina - its function is to nourish the retina

coalescence - the growing together or growth into one body of the materials being welded

cone, retinal - specialized visual cell in the retina; the cones are responsible for sharpness of vision and color vision

conjunctiva - the delicate membrane that lines the eyelids and covers the exposed surface of the eyeball

constricted arc (plasma arc welding and cutting) - a plasma arc column that is shaped by a constricting nozzle orifice

constricting nozzle (plasma arc welding and cutting) - a water cooled copper nozzle surrounding the electrode and containing the constricting orifice

constricting orifice (plasma arc welding and cutting) - the hole in the constricting nozzle through which the arc passes

contact tube - a device which transfers current to a continuous electrode

CO<sub>2</sub> welding - see preferred term gas metal arc welding

direct current electrode negative - the arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc - see also straight polarity

direct current electrode positive - the arrangement of direct current arc welding leads in which the work is the negative pole and the electrode is the positive pole of the welding arc - see also reverse polarity

direct current reverse polarity (DCRP) - see reverse polarity and direct current electrode positive

direct current straight polarity (DCSP) - see straight polarity and direct current electrode negative

electrode -

arc welding electrode - a component of the welding circuit through which current is conducted between the electrode holder and the arc

bare electrode - a filler metal electrode consisting of a single metal or alloy that has been produced into a wire, strip, or bar form and that has had no coating or covering applied to it other than that which was incidental to its manufacture or preservation

covered electrode - a composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied - the covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld

flux cored electrode - a composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidation, arc stabilization and slag formation - alloying materials may be included in the core - external shielding may or may not be used

metal cored electrode - a composite filler metal electrode consisting of a metal tube or other hollow configuration containing alloying ingredients - minor amounts of ingredients providing such functions as arc stabilization and fluxing of oxides may be included - external shielding gas may or may not be used

tungsten electrode - a non-filler metal electrode used in arc welding or cutting, made principally of tungsten

electrode extension (gas metal arc welding, flux cored arc welding, submerged arc welding) - the length of unmelted electrode extending beyond the end of the contact tube during welding

electrode holder - a device used for mechanically holding the electrode while conducting current to it

electrode lead - the electrical conductor between the source of arc welding current and the electrode holder

electrode setback (plasma arc welding and cutting) - the distance the electrode is recessed behind the constricting orifice measured from the outer face of the nozzle

emmetropia - a state of perfect vision

etiology - the cause of a disease

flash blindness - temporary visual disturbance resulting from viewing an intense light source

flux cored arc welding (FCAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work - shielding is provided by a flux contained within the tubular electrode - additional shielding may or may not be obtained from an externally supplied gas or gas mixture - see flux cored electrode

flux cored electrode - see electrode

fovea - a depression or pit in the center of the macula; it is the area of clearest vision

fundus - the interior surface of a hollow organ, as the retina of the eye

fusion - the melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence

fusion welding - any welding process or method which used fusion to complete the weld

gas metal arc welding (GMAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work - shielding is obtained entirely from an externally supplied gas or gas mixture - some methods of this process are called MIG or CO<sub>2</sub> welding

gas tungsten arc welding (GTAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work - shielding is obtained from a gas or gas mixture - pressure may or may not be used and filler metal may or may not be used (this process has sometimes been called TIG welding)

ground connection - an electrical connection of the welding machine frame to the earth for safety - see also work connection and work lead

ground lead - see preferred term work lead

gun - arc welding gun - in semiautomatic, machine, and automatic welding, a manipulating device to transfer current and guide the electrode into the arc - it may include provisions for shielding and arc initiation

heat-affected zone - that portion of the base metal which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or cutting

inert gas - a gas which does not normally combine chemically with the base metal or filler metal - see also protective atmosphere

inert-gas metal arc welding - see preferred term gas metal arc welding

inert-gas tungsten arc welding - see preferred term gas tungsten arc welding

infrared radiation - electromagnetic energy with wavelengths from 770 nm to 12000 nanometers

iritis - inflammation of the iris

irradiance - (E) - radiant flux (radiant power) per unit area incident upon a given surface [units of W/cm<sup>2</sup>]

keratitis - inflammation of the cornea; usually characterized by loss of transparency and dullness

keyhole - a technique of welding in which a concentrated heat source penetrates completely through a workpiece forming a hole at the leading edge of the molten weld metal - as the heat source progresses, the molten metal fills in behind the hole to form the weld bead

lens, crystalline - lens of the eye: a transparent biconvex body situated between the anterior chamber (aqueous) and the posterior chamber (vitreous) through which the light rays are further focused on the retina - the cornea provides most of the refractive power of the eye

lenticular (adj) - pertaining to the lens of the eye

machine welding - welding with equipment which performs the welding operation under the constant observation and control of a welding operator - the equipment may or may not perform the loading and unloading of the work

macula - an oval area in the center of the retina devoid of blood vessels; the area most responsible for color vision

manual welding - a welding operation performed and controlled completely by hand

MIG welding - see preferred terms gas metal arc welding, flux cored arc welding

miosis - reduction in the size of the pupil

molten weld pool - the liquid state of a weld prior to solidification as weld metal

nanometer -  $10^{-9}$  meter, preferred unit for wavelength in the ultraviolet, visible and near-infrared spectral region

nontransferred arc (plasma arc welding and cutting, and thermal spraying) - an arc established between the electrode and the constricting nozzle - the workpiece is not in the electrical circuit - see transferred arc

nozzle - a device which directs shielding media

opacity - the condition of being nontransparent, a cataract

open-circuit voltage - the voltage between the output terminals of the welding machine when no current is flowing in the welding circuit

ophthalmologist - a medical practitioner specializing in the medical and surgical care of the eyes

ophthalmoscopy, direct - the observation of an upright mirrored image of the interior of the eye through the use of an ophthalmoscope

ophthalmoscopy, indirect - the observation of an inverted image of the interior of the eye

optic disc - the portion of the optic nerve within the eye which is formed by the meeting of all the retinal nerve fibers at the level of the retina

orbit - the cavity in the skull which contains the eyeball

orifice gas (plasma arc welding and cutting) - the gas that is directed into the torch to surround the electrode - it becomes ionized in the arc to form the plasma, and issues from the orifice in the torch nozzle as the plasma jet

orifice throat length (plasma arc welding and cutting) - the length of the constricting orifice

parent metal - see preferred term base metal

photophobia - abnormal sensitivity to and discomfort from light

pigment epithelium - a layer of cells in the retina containing pigment granules

pilot arc (plasma arc welding) - a low current continuous arc between the electrode and the constricting nozzle to ionize the gas and facilitate the start of the main welding arc

plasma - a gas that has been heated to an at least partially ionized condition, enabling it to conduct an electric current

plasma arc cutting (PAC) - an arc cutting process which severs metal by melting a localized area with a constricted arc and removing the molten material with a high velocity jet of hot, ionized gas issuing from the orifice

plasma arc welding (PAW) - an arc welding process which produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc) - shielding is obtained from the hot, ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas - shielding gas may be an inert gas or a mixture of gases - pressure may or may not be used, and filler metal may or may not be supplied

plenum (plasma arc welding and cutting, and thermal spraying) - the space between the inside wall of the constricting nozzle and the electrode

polarity - see direct current electrode negative, direct current electrode positive, straight polarity, and reverse polarity

protective atmosphere - a gas envelope surrounding the part to be brazed, welded or thermal sprayed, with the gas composition controlled with respect to chemical composition, dew point, pressure, flow rate, etc

pterygium - a growth of the conjunctiva considered to be due to a degenerative process caused by long continued irritation as from exposure to wind, dust, and possibly to ultraviolet radiation

puddle - see preferred term molten weld pool

pupil - the opening at the center of the iris of the eye for the transmission of light - the pupil size varies from 2 mm to 8 mm

radiance - (L) - radiant flux (power) output per unit solid angle per unit area [units of W/cm<sup>2</sup>·sr)]

retina - the innermost coat of the posterior part of the eyeball, surrounding the vitreous body and responsible for vision

reverse polarity - the arrangement of direct current arc welding leads with the work as the negative pole and the electrode as the positive pole of the welding arc

sclera - the tough, white, protective coat of the eye

scotoma - a blind or partially blind area in the visual field

semiautomatic arc welding - arc welding with equipment which controls only the filler metal feed - the advance of the welding is manually controlled

shielded metal arc welding (SMAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the work - shielding is obtained from decomposition of the electrode covering - pressure is not used and filler metal is obtained from the electrode

shielding gas - protective gas used to prevent atmospheric contamination

slit-lamp - an instrument producing a slender beam of light for illuminating any reasonably transparent structure, as the cornea, or lens

stick electrode - see electrode: covered electrode

stick electrode welding - see preferred term shielded metal arc welding

stickout - see preferred term electrode extension

strabismus - squint; failure of the two eyes simultaneously to direct their gaze at the same object because of muscle imbalance

straight polarity - the arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc - a synonym for direct current electrode negative

substrate - any base material to which a thermal sprayed coating or surfacing weld is applied

tear film - microscopically thin lipid film which constantly bathes cornea

torch - see preferred terms welding torch, cutting torch, spray torch

transferred arc (plasma arc welding) - a plasma arc established between the electrode and the workpiece

tungsten electrode - see electrode: tungsten electrode

vision, photopic - vision attributed to cone function characterized by the ability to discriminate colors and small detail; daylight vision

vision, scotopic - vision attributed to rod function characterized by the lack of ability to discriminate colors and small detail and effective primarily in the detection of movement and low luminous intensities - night vision

visual acuity - ability of the eye to sharply perceive the shape of objects in the direct line of vision

visual axis - the central line of gaze

visual cortex - final station of visual impulses in the brain; sensory area of brain responsible for vision

visual field - the area of physical space visible to an eye in a given position

vitreous or vitreous body - transparent, colorless mass of soft gelatinous material filling the posterior chamber of the eyeball (behind the lens)

weld - a localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler material

welder - one who performs a manual or semiautomatic welding operation (sometimes erroneously used to denote a welding machine)

welding - a materials joining process used in making welds (see the Master Chart of Welding and Allied Processes)

welding current - the current in the welding circuit during the making of a weld - in resistance welding, the current used during a preweld or postweld interval is excluded

welding electrode - see preferred term electrode

welding generator - a generator used for supplying current for welding

welding ground - see preferred term work connection

welding head - the part of a welding machine or automatic welding equipment in which a welding gun or torch is incorporated

welding leads - the work lead and electrode lead of an arc welding circuit

welding machine - equipment used to perform the welding operation - for example, spot welding machine, arc welding machine, seam welding machine, etc

welding operator - one who operates machine or automatic welding equipment

welding procedure - the detailed methods and practices including all joint welding procedures involved in the production of a weldment

welding process - a materials joining process which produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal (see the Master Chart of Welding and Allied Processes)

welding retifier - a device in a welding machine for converting alternating current to direct current

welding rod - a form of filler metal used for welding or brazing which does not conduct the electrical current

welding tip - a welding torch tip designed for welding

welding torch - a device used in oxyfuel gas welding or torch brazing for mixing and controlling the flow of gases

welding transformer - a transformer used for supplying current for welding

welding wire - see preferred terms electrode and welding rod

weld metal - that portion of a weld which has been melted during welding

weld metal area - the area of the weld metal as measured on the cross section of a weld

weldor - see preferred term welder

wire feed speed - the rate of speed in mm/s or in/min at which a filler metal is consumed in arc welding or thermal spraying

wire straightener - a device used for controlling the cast of coiled wire to enable it to be easily fed into the gun

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work connection - the connection of the work lead to the work

work lead - the electric conductor between the source of arc welding current  
and the work

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APPENDIX C

TABLE 1. WELDING PARAMETERS FOR EVENTS 1 to 7.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 300 A

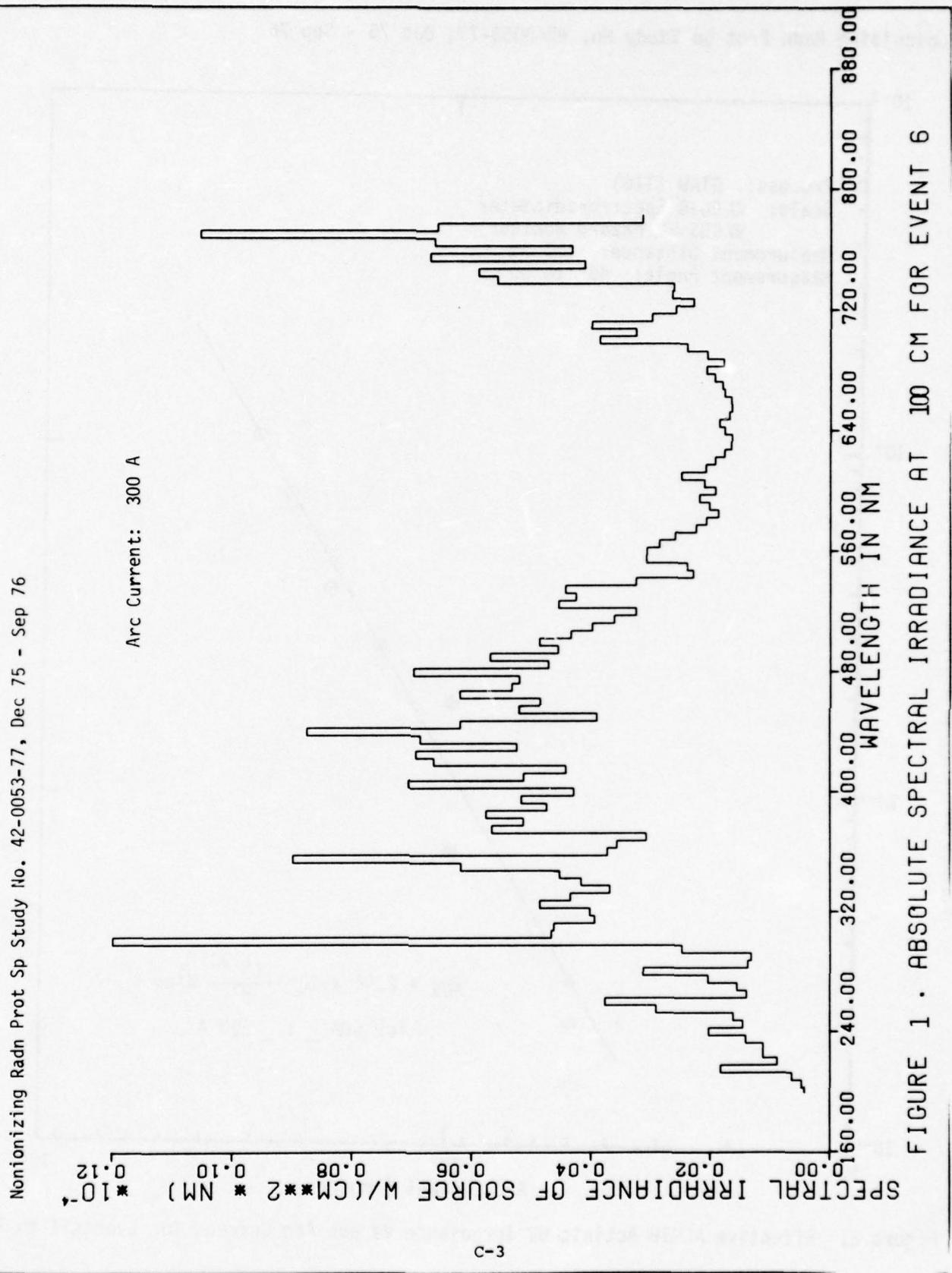
Polarity: DCSP

Shielding Gas: Ar at 20 cfm

Arc Length: 1/16" (0.062" to 0.089")

Electrode Diameter: 1/16" (50 to 100A), 3/32"  
(150 to 200A), and 1/8"  
(250 to 300A)

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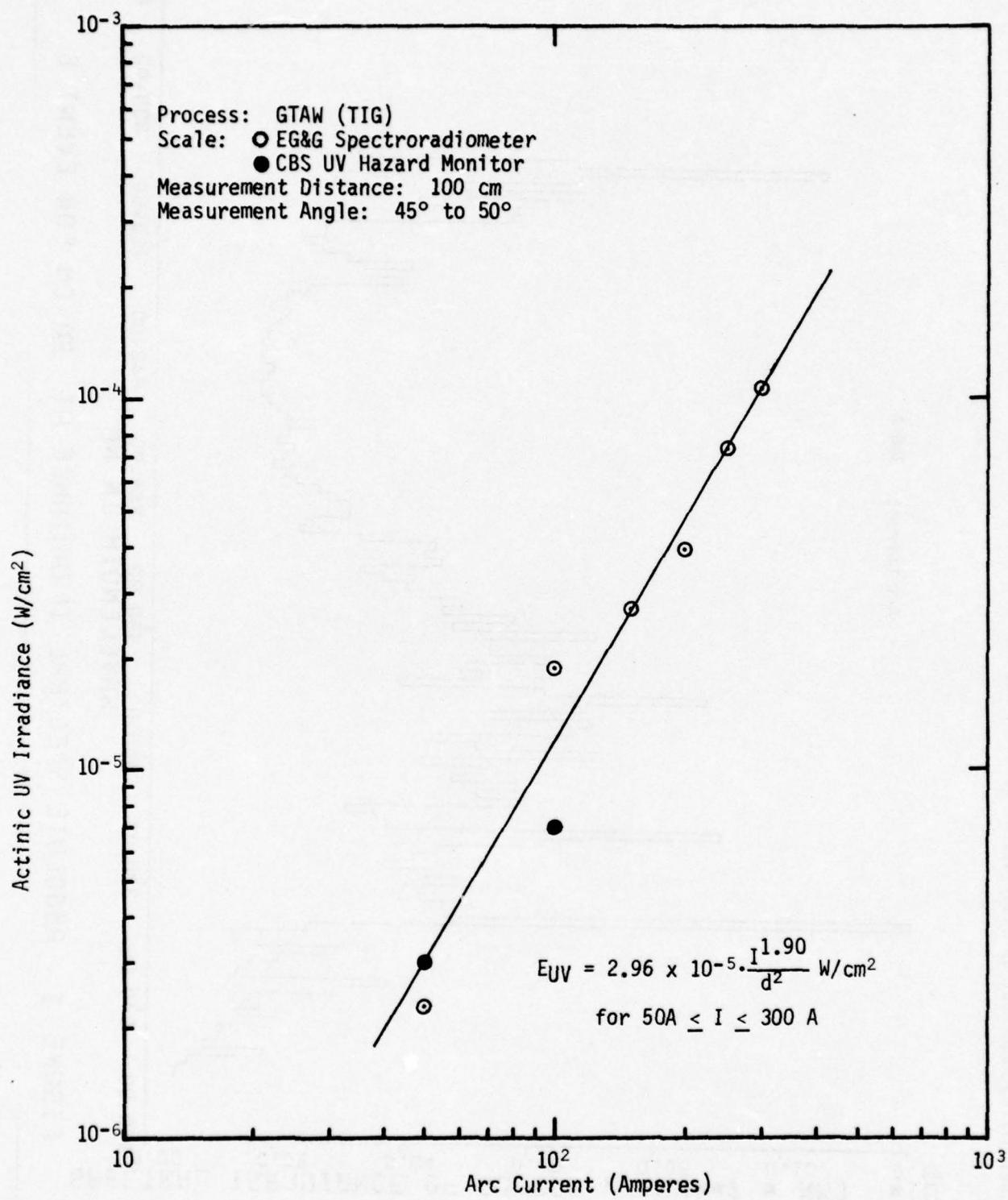


Figure 2. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 1 to 7.

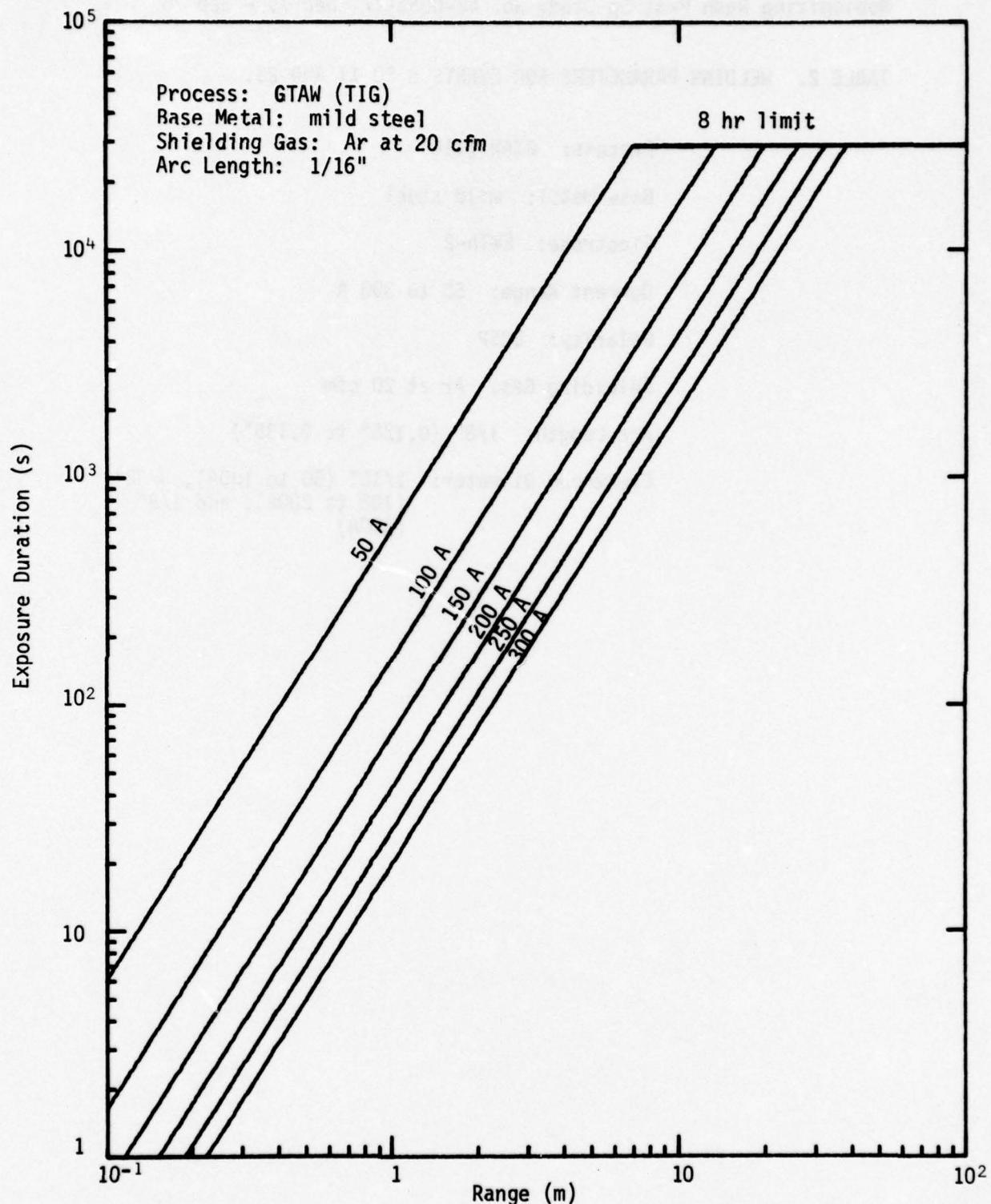


Figure 3. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 1 to 7.

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TABLE 2. WELDING PARAMETERS FOR EVENTS 8 TO 11 AND 23.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 300 A

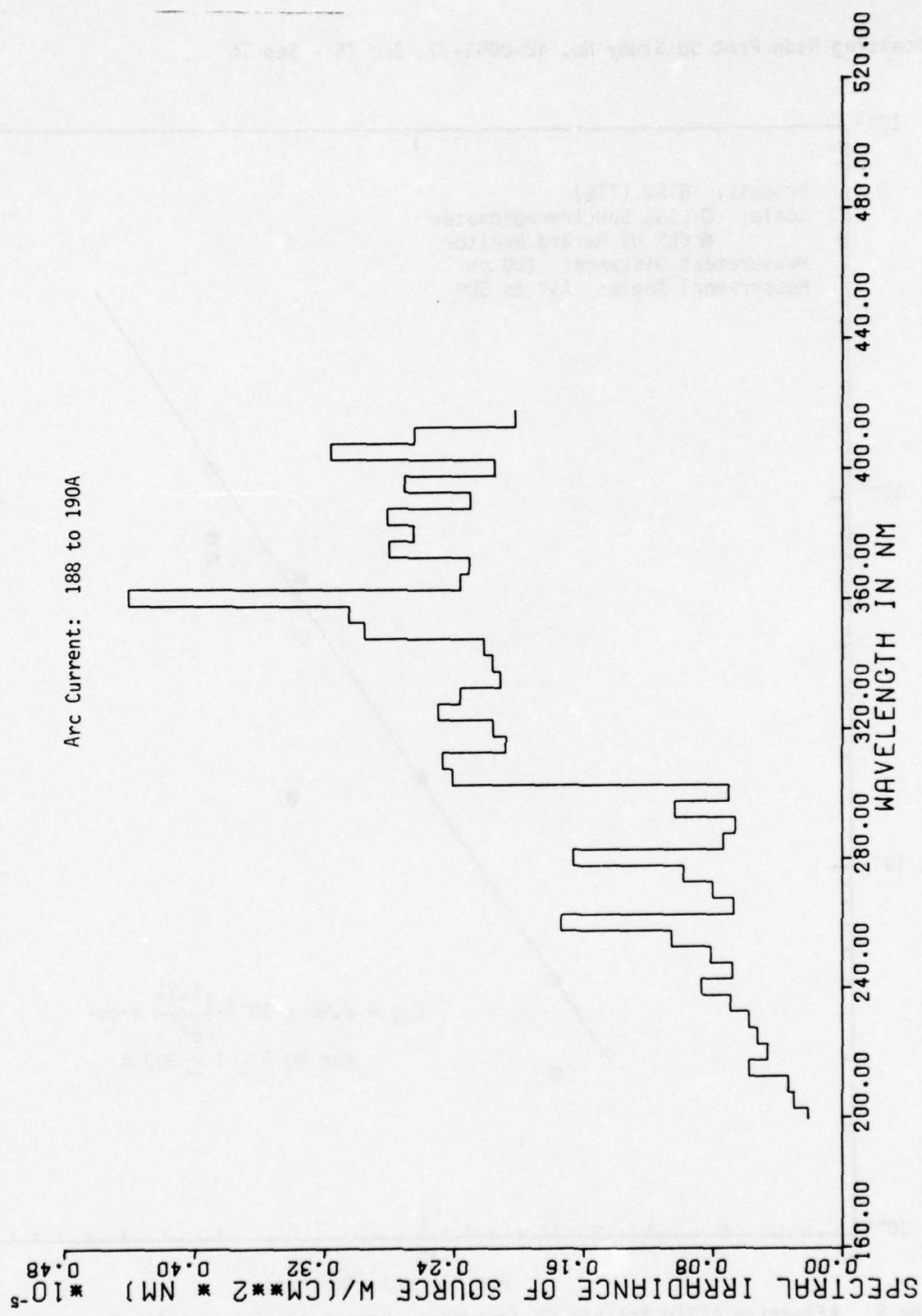
Polarity: DCSP

Shielding Gas: Ar at 20 cfm

Arc Length: 1/8" (0.125" to 0.135")

Electrode Diameter: 1/16" (50 to 100A), 3/32"  
(188 to 200A), and 1/8"  
(300A)

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FIGURE 4. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 10

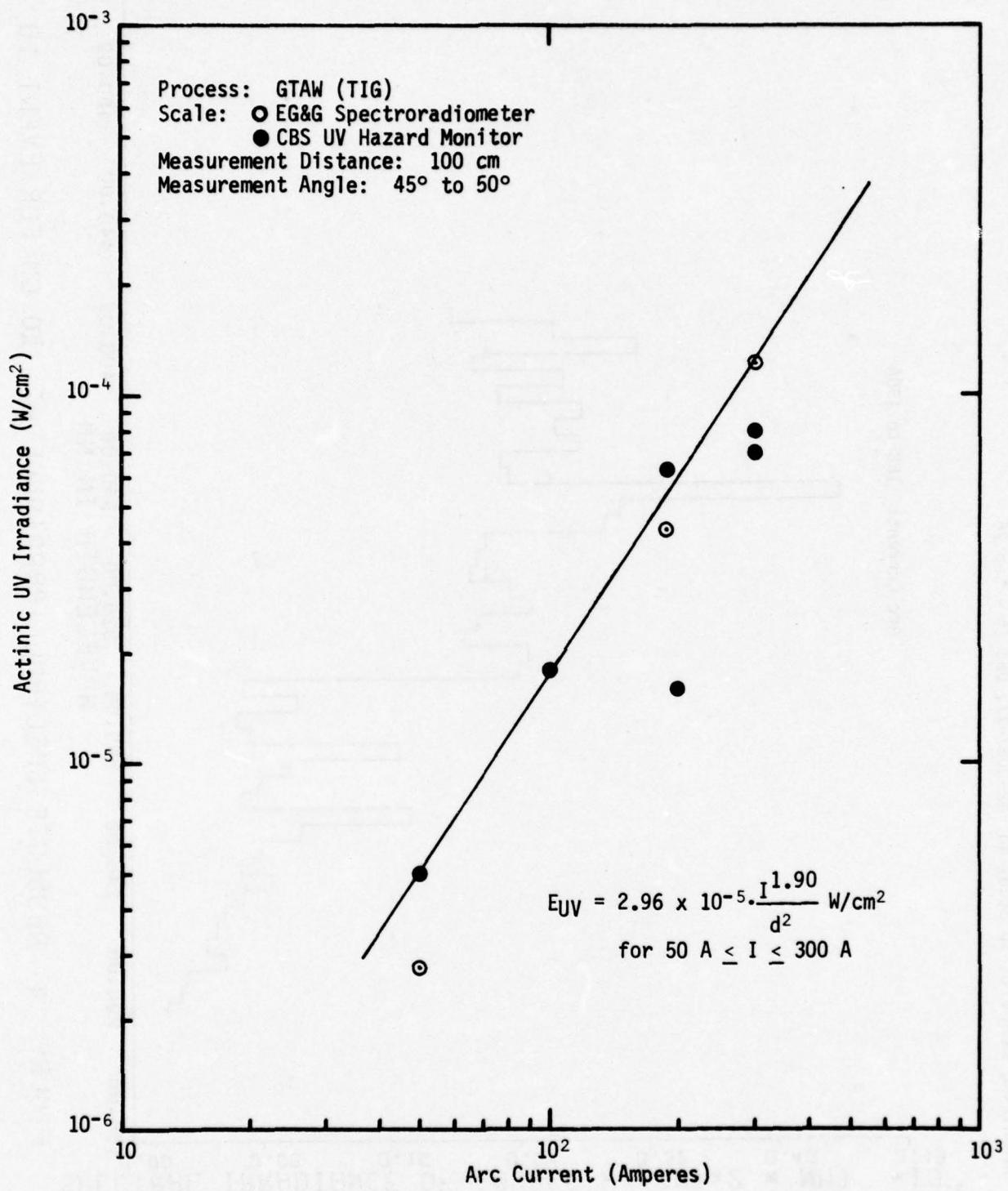


Figure 5. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 8 to 11 and 23.

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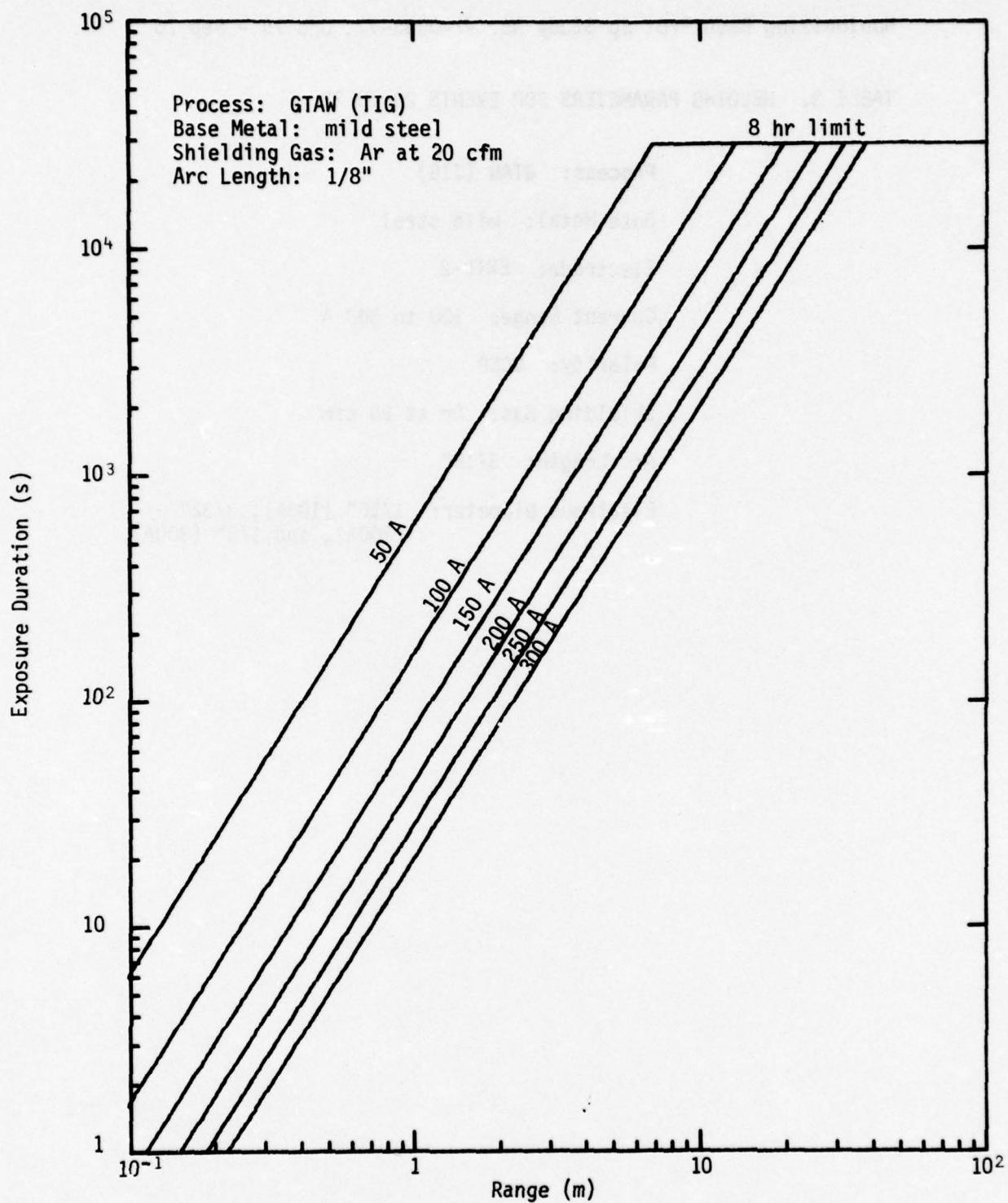


Figure 6. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 8 to 11 and 23.

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TABLE 3. WELDING PARAMETERS FOR EVENTS 20 TO 22.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 100 to 300 A

Polarity: DCSP

Shielding Gas: Ar at 20 cfm

Arc Length: 3/16"

Electrode Diameter: 1/16" (100A), 3/32"  
(200A), and 1/8" (300A)

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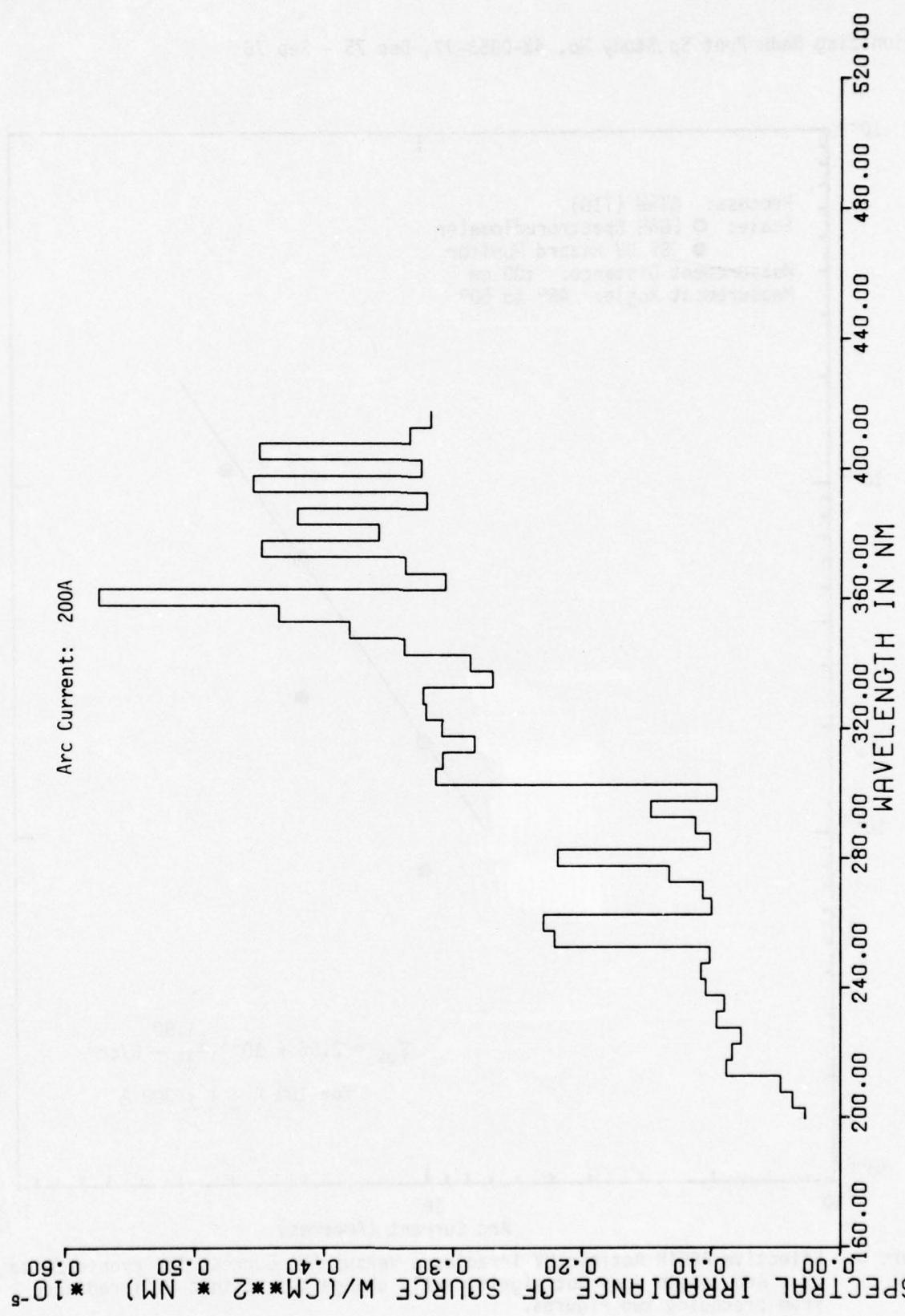


FIGURE 7 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 21

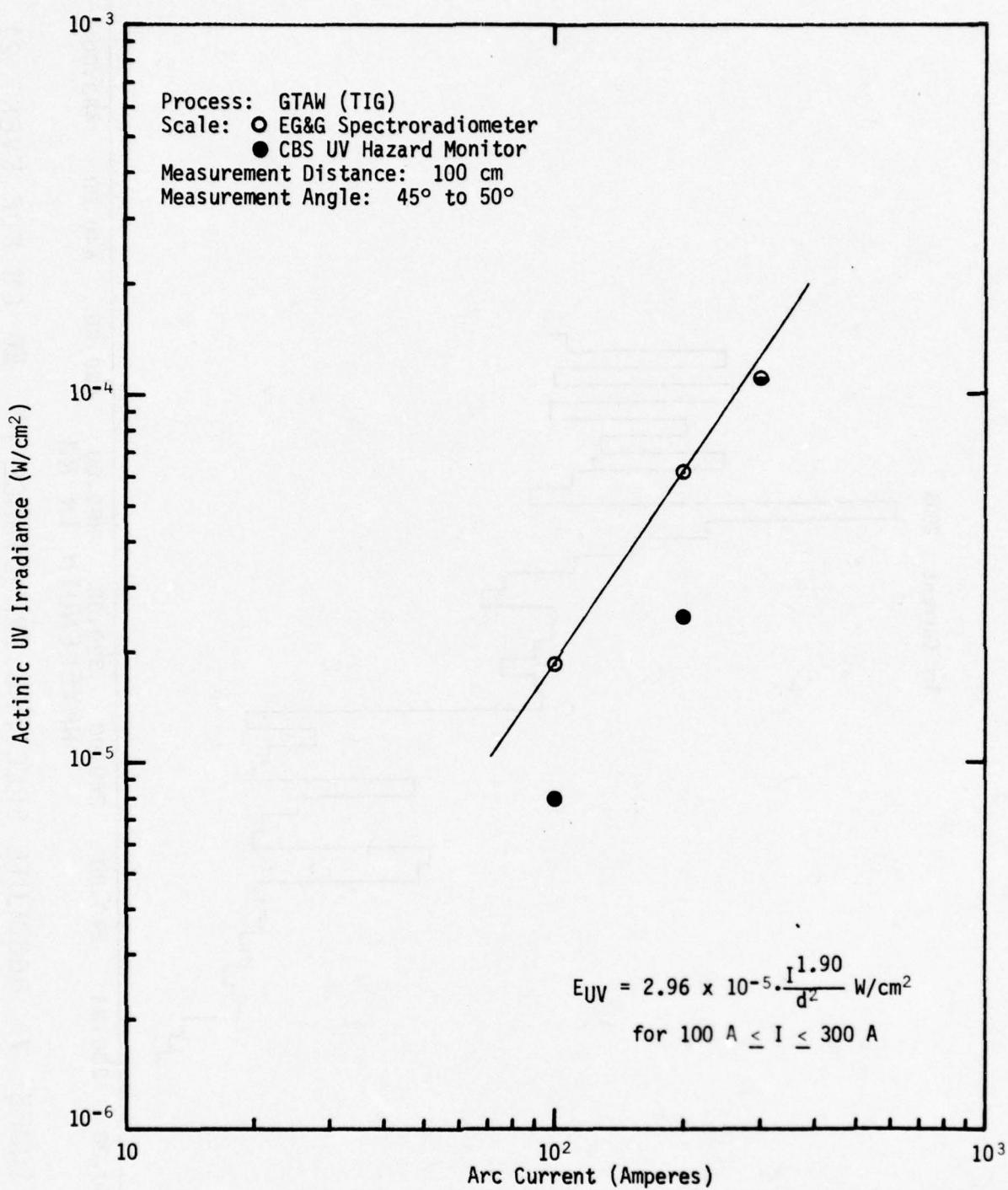


Figure 8. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 20 to 22. Arc length does not significantly change the actinic UV irradiance from preceding two Figures.

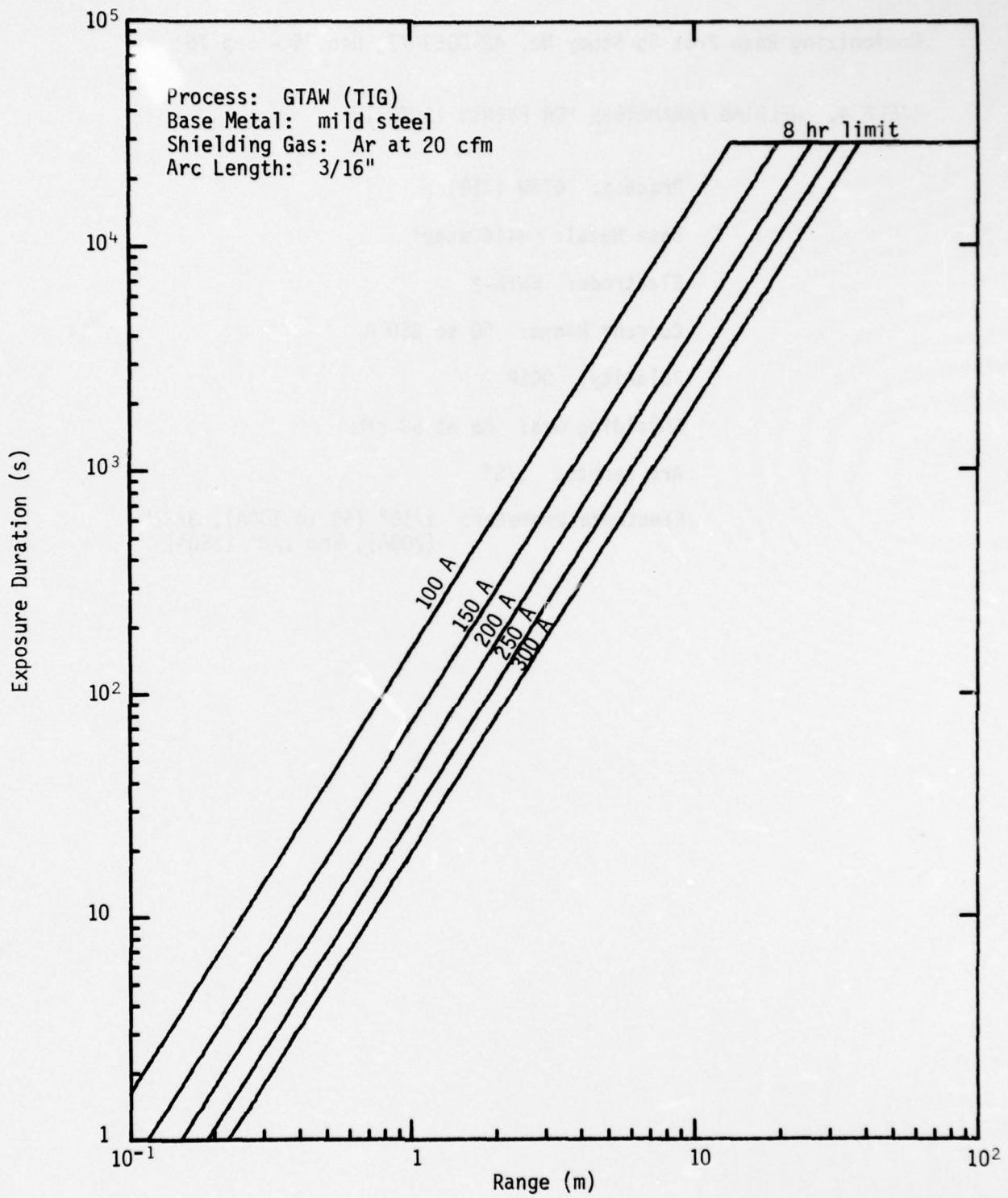


Figure 9. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 20 to 22.

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TABLE 4. WELDING PARAMETERS FOR EVENTS 12 TO 15

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 250 A

Polarity: DCSP

Shielding Gas: He at 50 cfm

Arc Length: 1/8"

Electrode Diameter: 1/16" (50 to 100A), 3/32"  
(200A), and 1/8" (250A)

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Arc Current: 250A

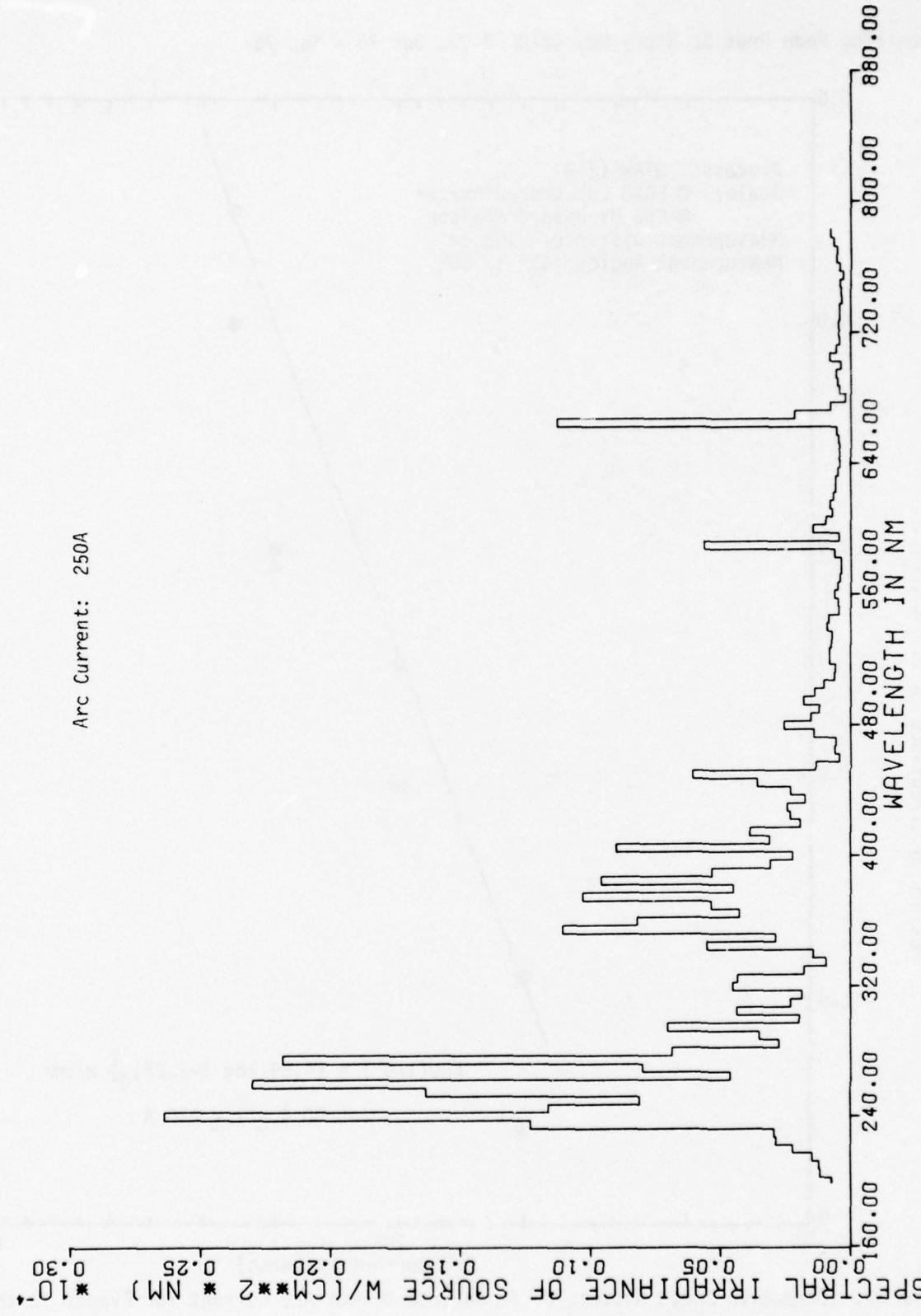


FIGURE 10 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 12

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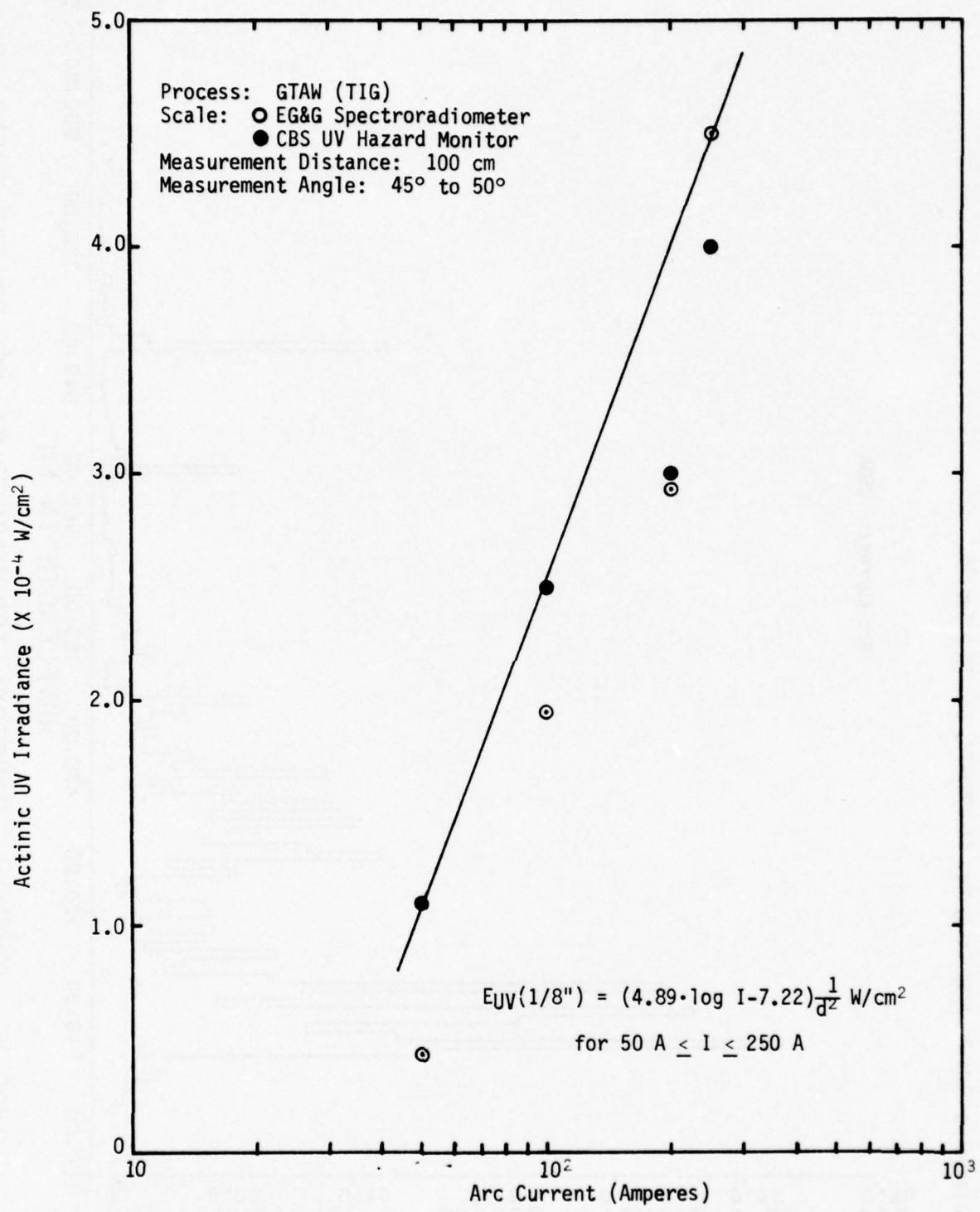


Figure 11. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 12 to 15.

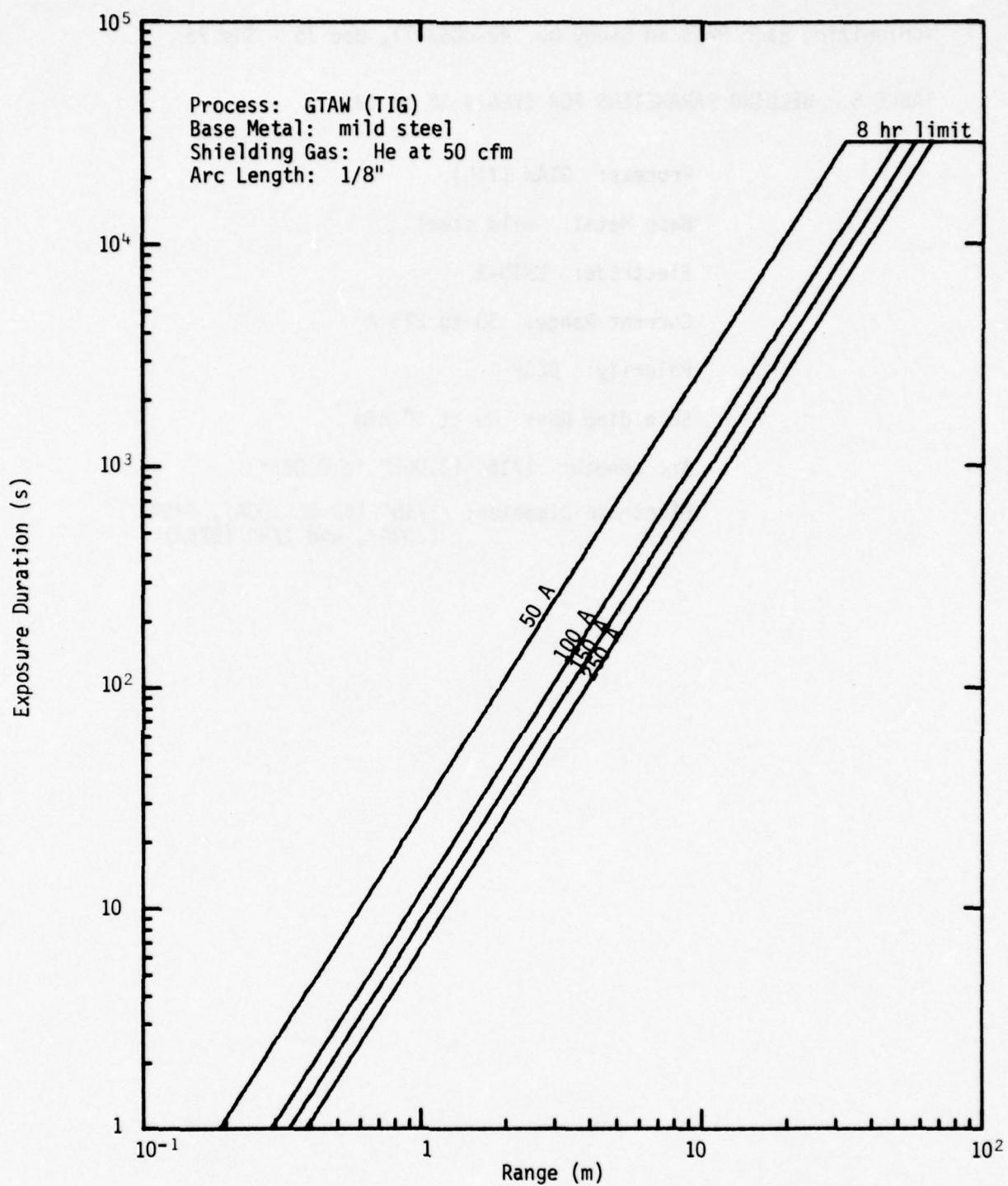


Figure 12. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 12 to 15.

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TABLE 5. WELDING PARAMETERS FOR EVENTS 16 TO 19.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 275 A

Polarity: DCSP

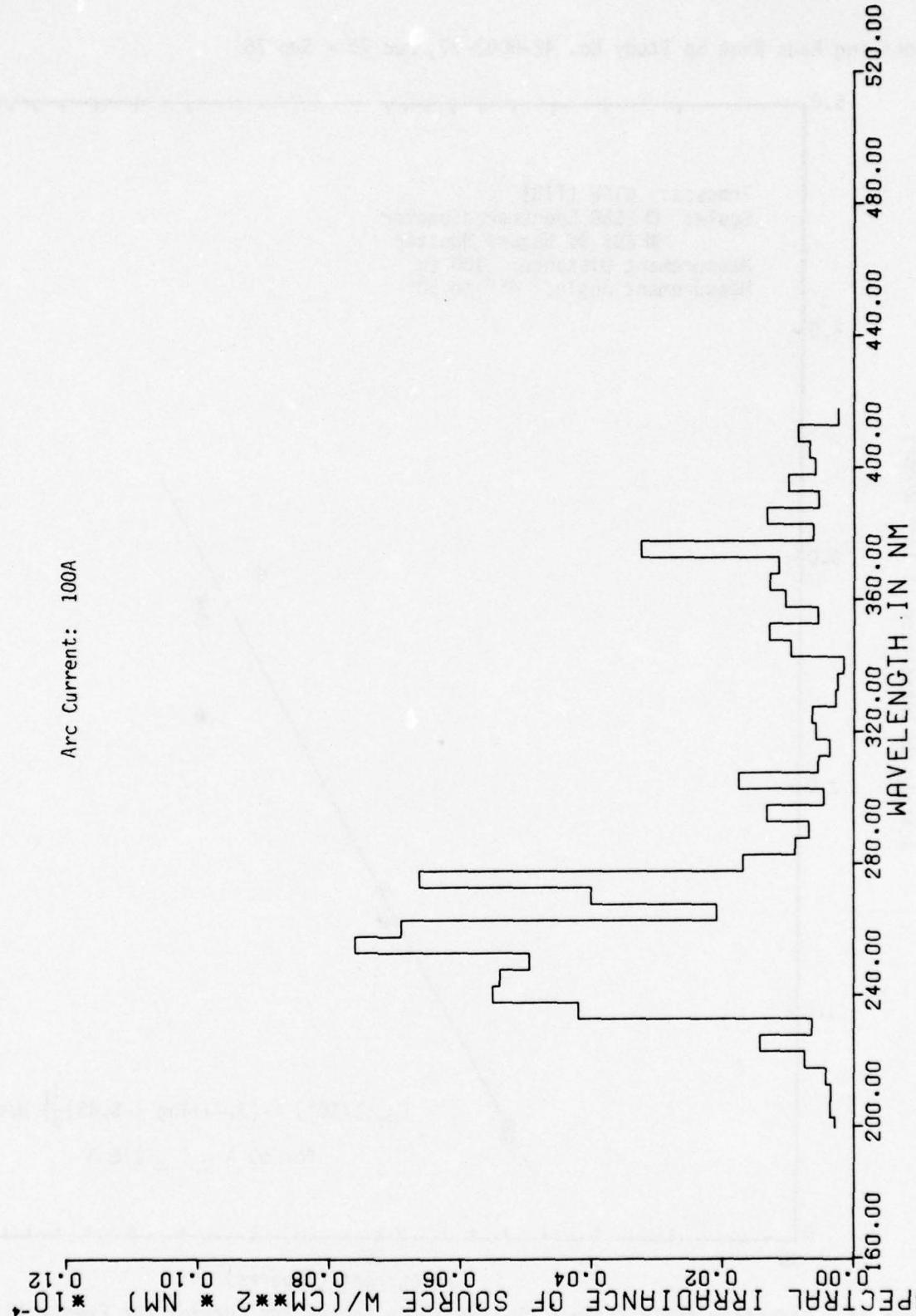
Shielding Gas: He at 50 cfm

Arc Length: 1/16" (0.062" to 0.083")

Electrode Diameter: 1/16" (50 to 100A), 3/32"  
(200A), and 1/8" (275A)

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Arc Current: 100A



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FIGURE 13 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 17

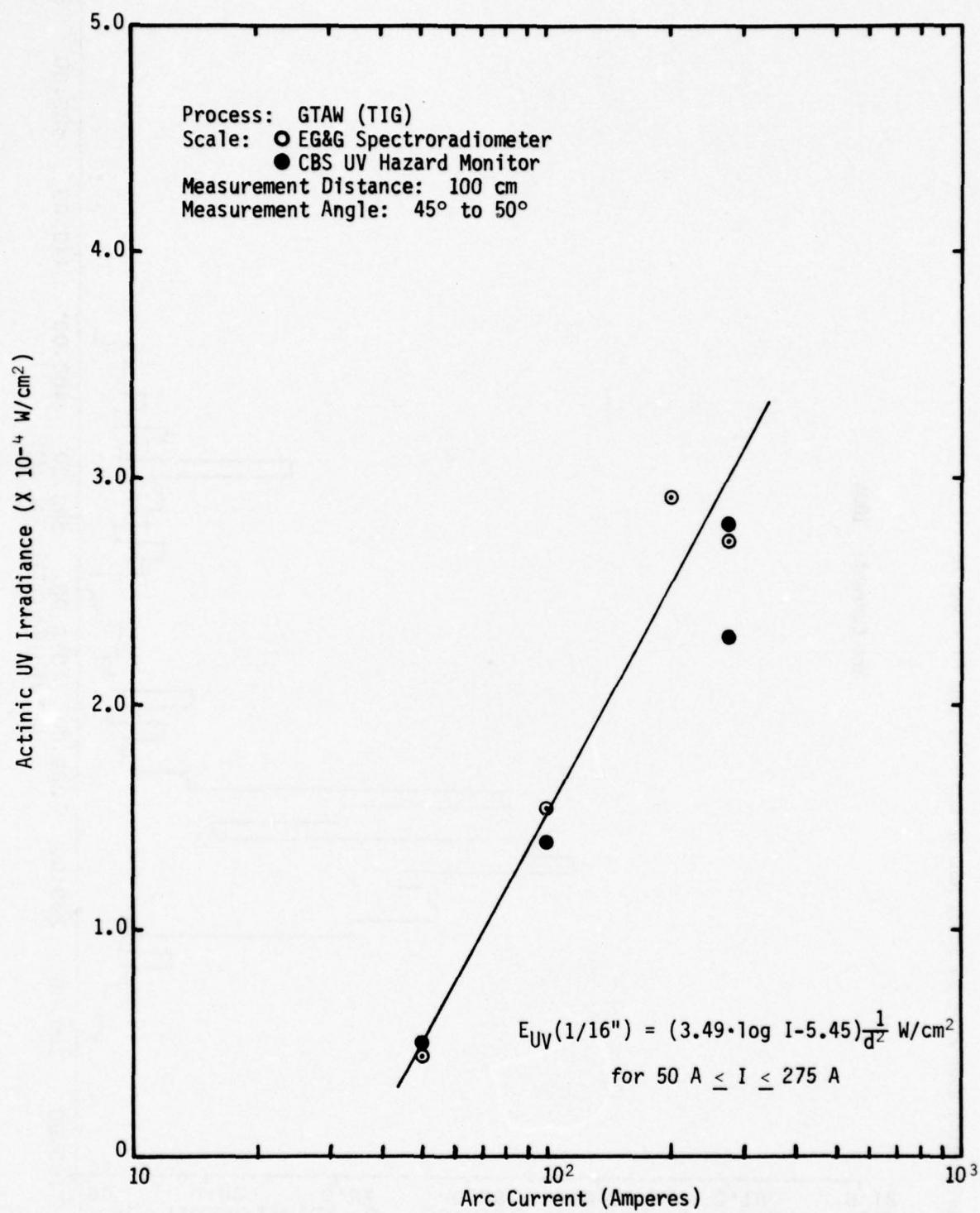
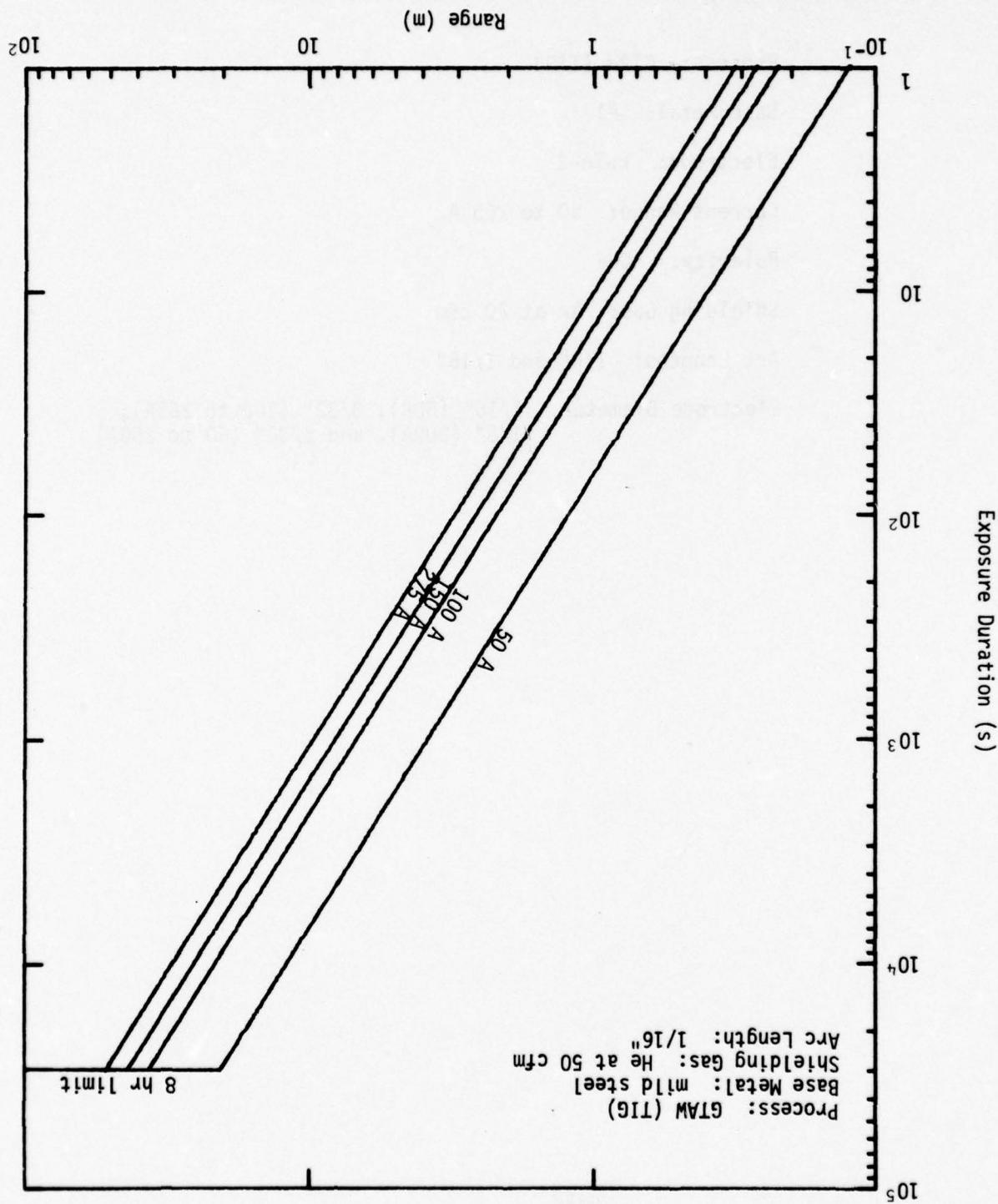


Figure 14. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 16 to 19. The irradiance increases with arc length from preceding figure.

Figure 15. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 16 to 19.



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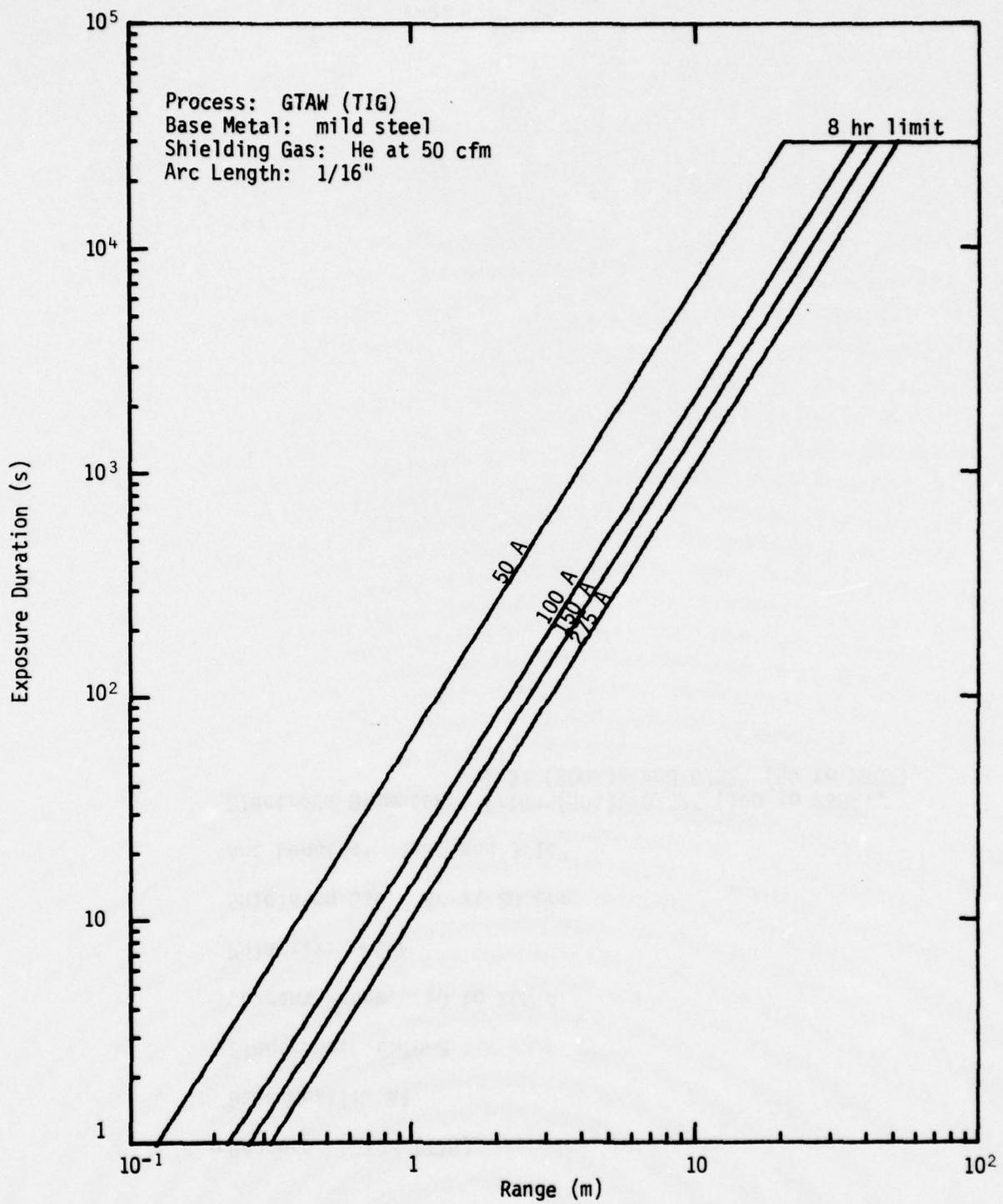


Figure 15. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 16 to 19.

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TABLE 6. WELDING PARAMETERS FOR EVENTS 24 TO 28 AND 31 TO 33.

Process: GTAW (TIG)

Base Metal: Al

Electrode: EWTh-2

Current Range: 50 to 265 A

Polarity: ACHF

Shielding Gas: Ar at 20 cfm

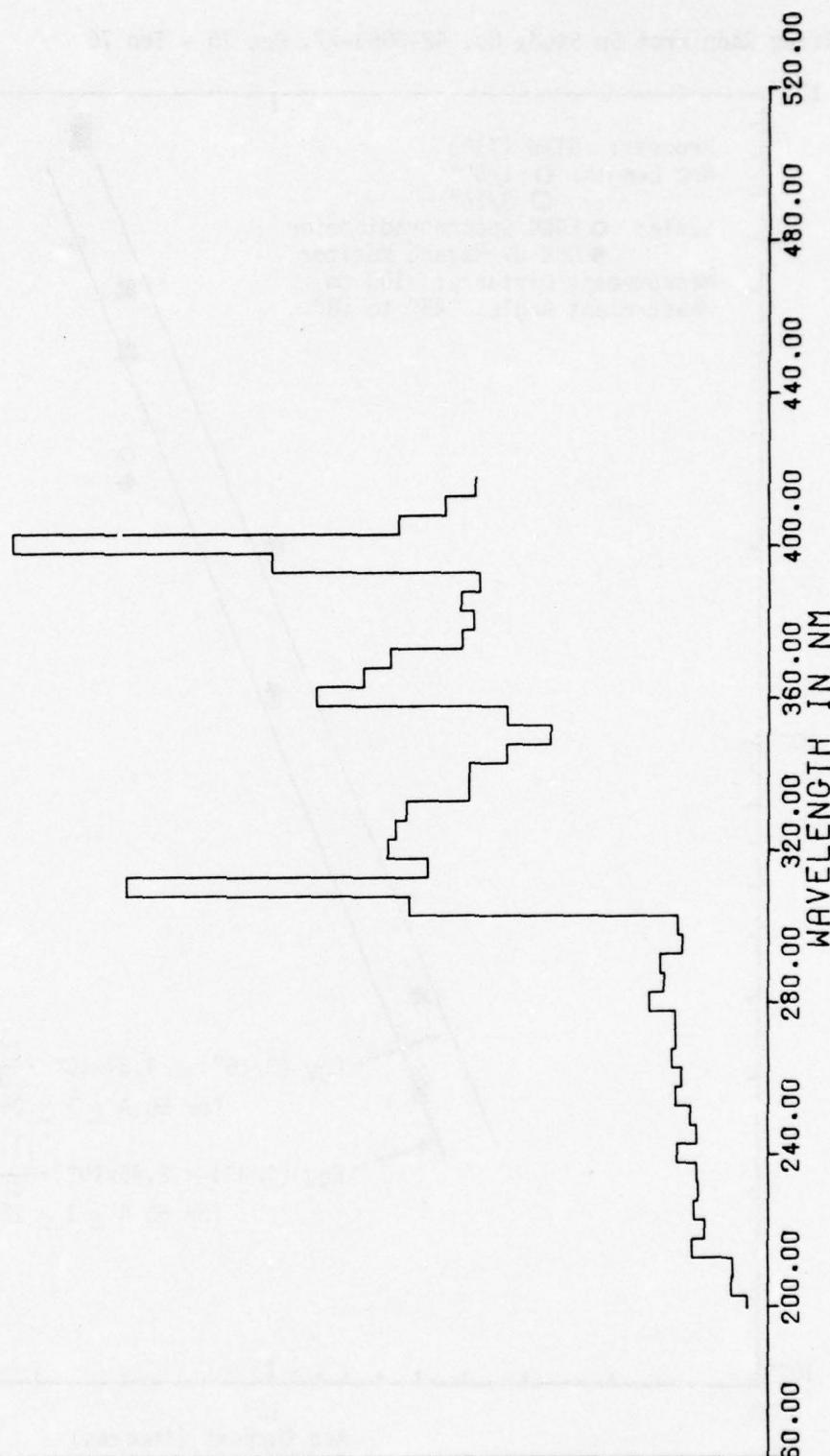
Arc Lengths: 1/8" and 3/16"

Electrode Diameter: 1/16" (50A), 3/32" (100 to 265A),  
1/8" (200A), and 5/32" (50 to 250A)

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Arc Current: 100A  
Arc Length: 1/8"

SPECTRAL IRRADIANCE OF SOURCE W/(CM<sup>2</sup> \* NM) \* 10<sup>-6</sup>



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FIGURE 16 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 25

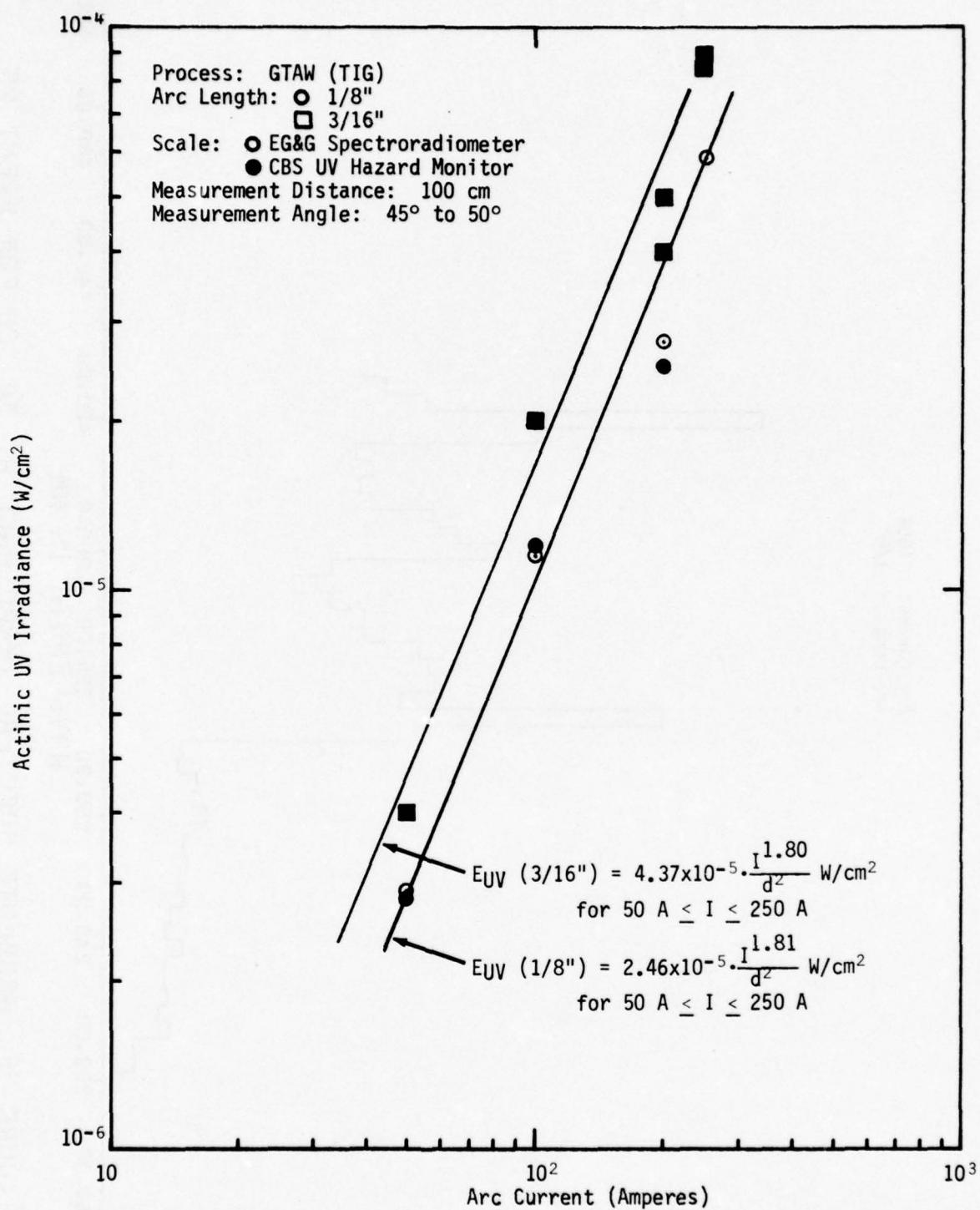


Figure 17. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 24 to 28 and 31 to 33. The irradiance increases with arc length but does not significantly vary with electrode diameter.

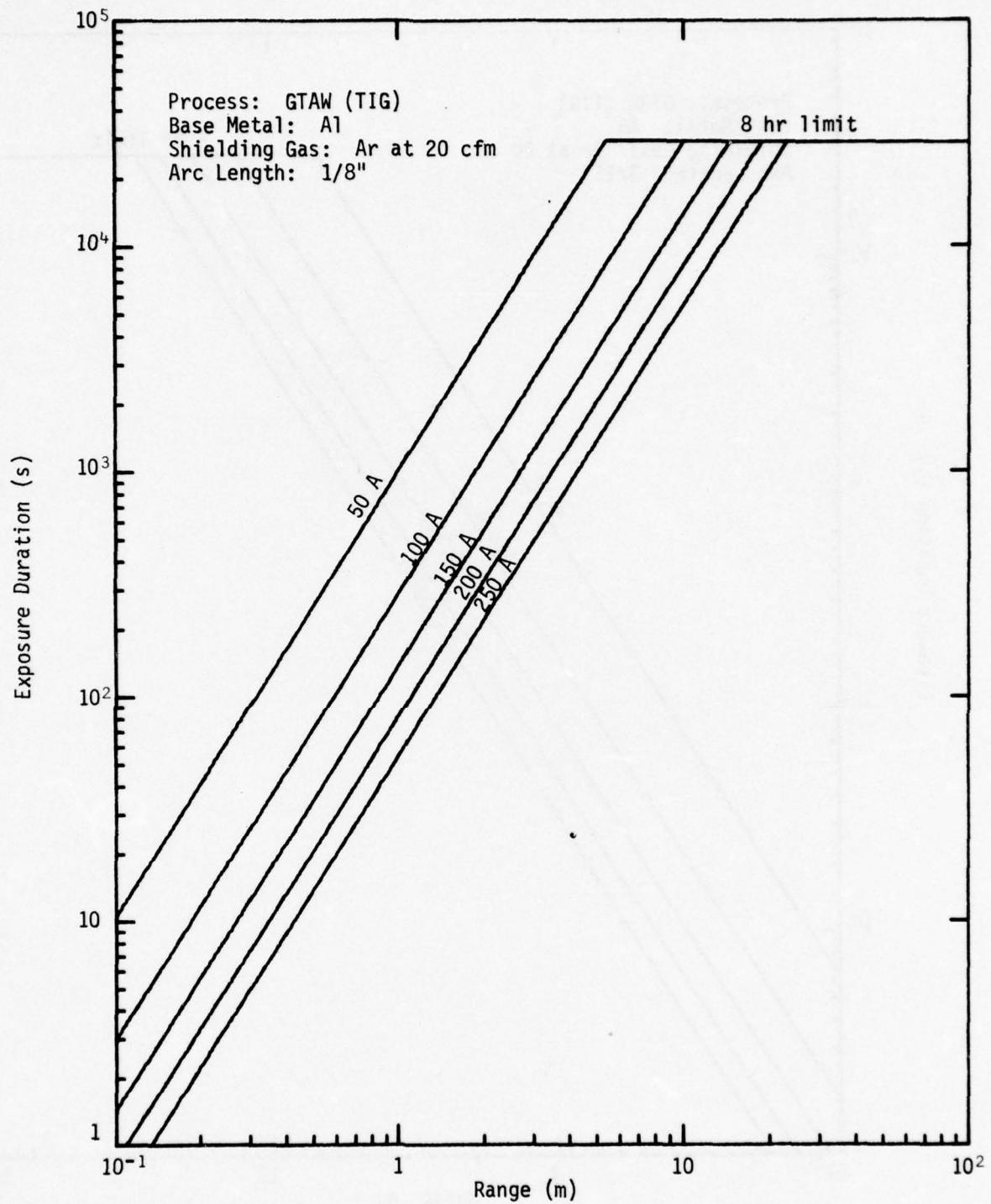


Figure 18. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 24 to 28 and 31 to 33.

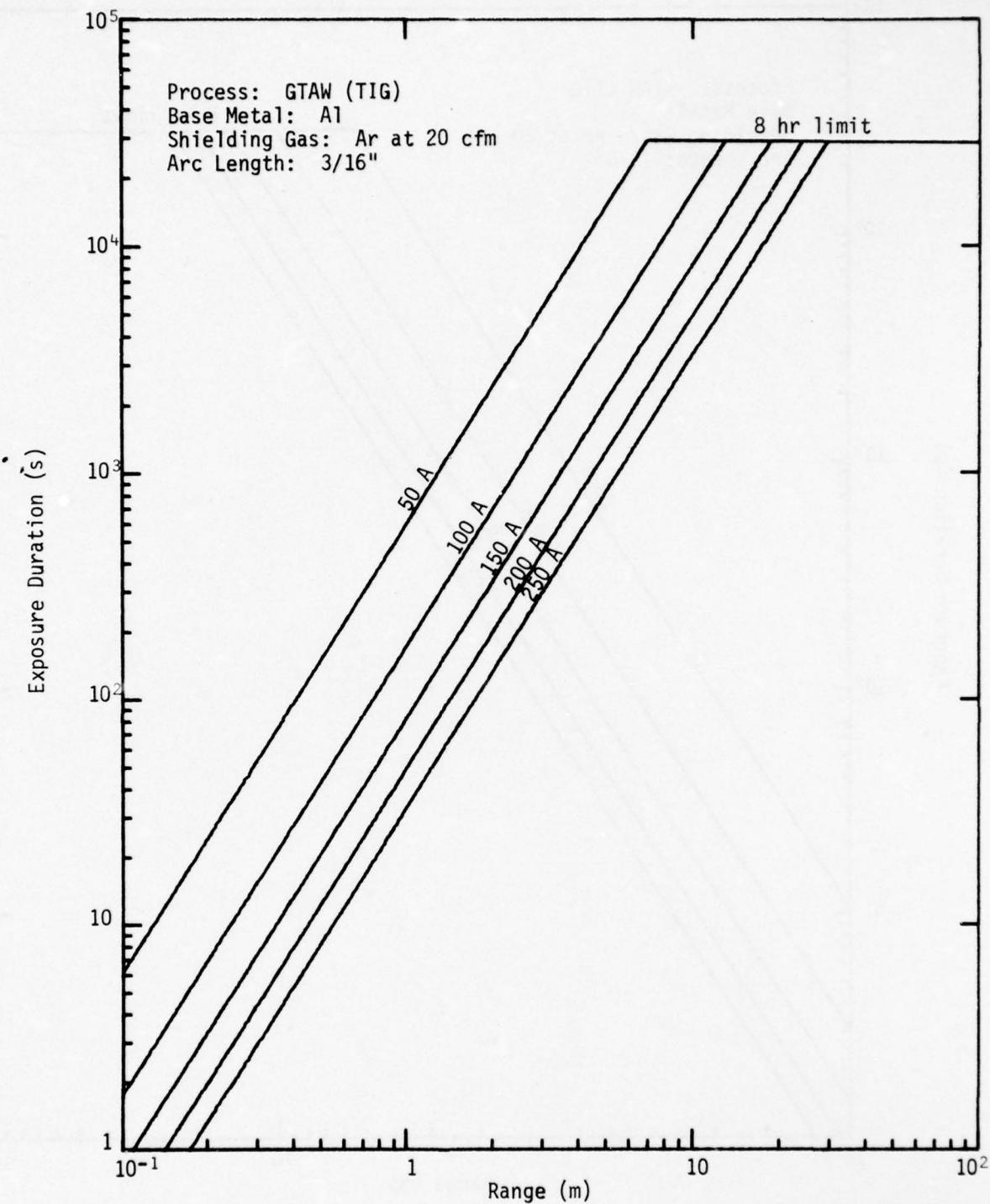


Figure 19. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 24 to 28 and 31 to 33.

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TABLE 7. WELDING PARAMETERS FOR EVENTS 34 TO 39.

Process: GTAW (TIG)

Base Metal: Al

Electrode: EWTh-2

Current Range: 50 to 200 A

Polarity: ACHF

Shielding Gas: He at 50 cfm

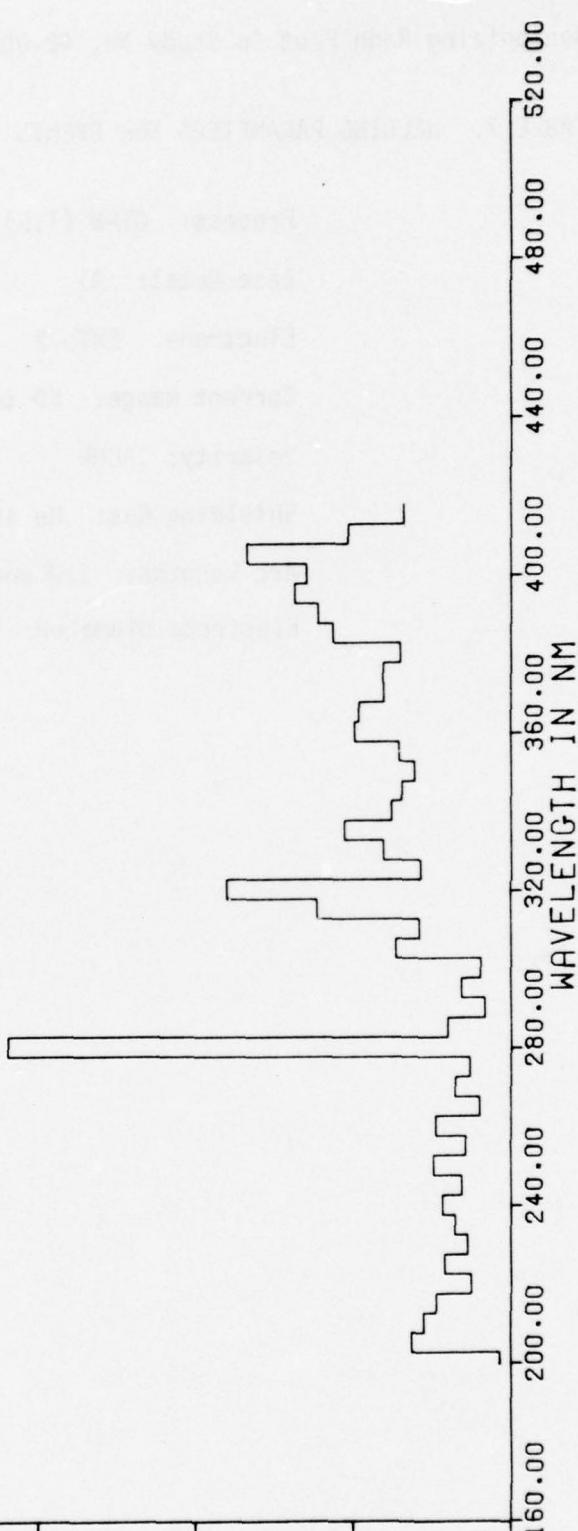
Arc Lengths: 1/8" and 3/16"

Electrode Diameter: 5/32"

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SPECTRAL IRRADIANCE OF SOURCE W/(CM\*\*2 \* NM) \*10<sup>-6</sup>

Arc Current: 100A  
Arc Length: 1/8"



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FIGURE 20 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 36

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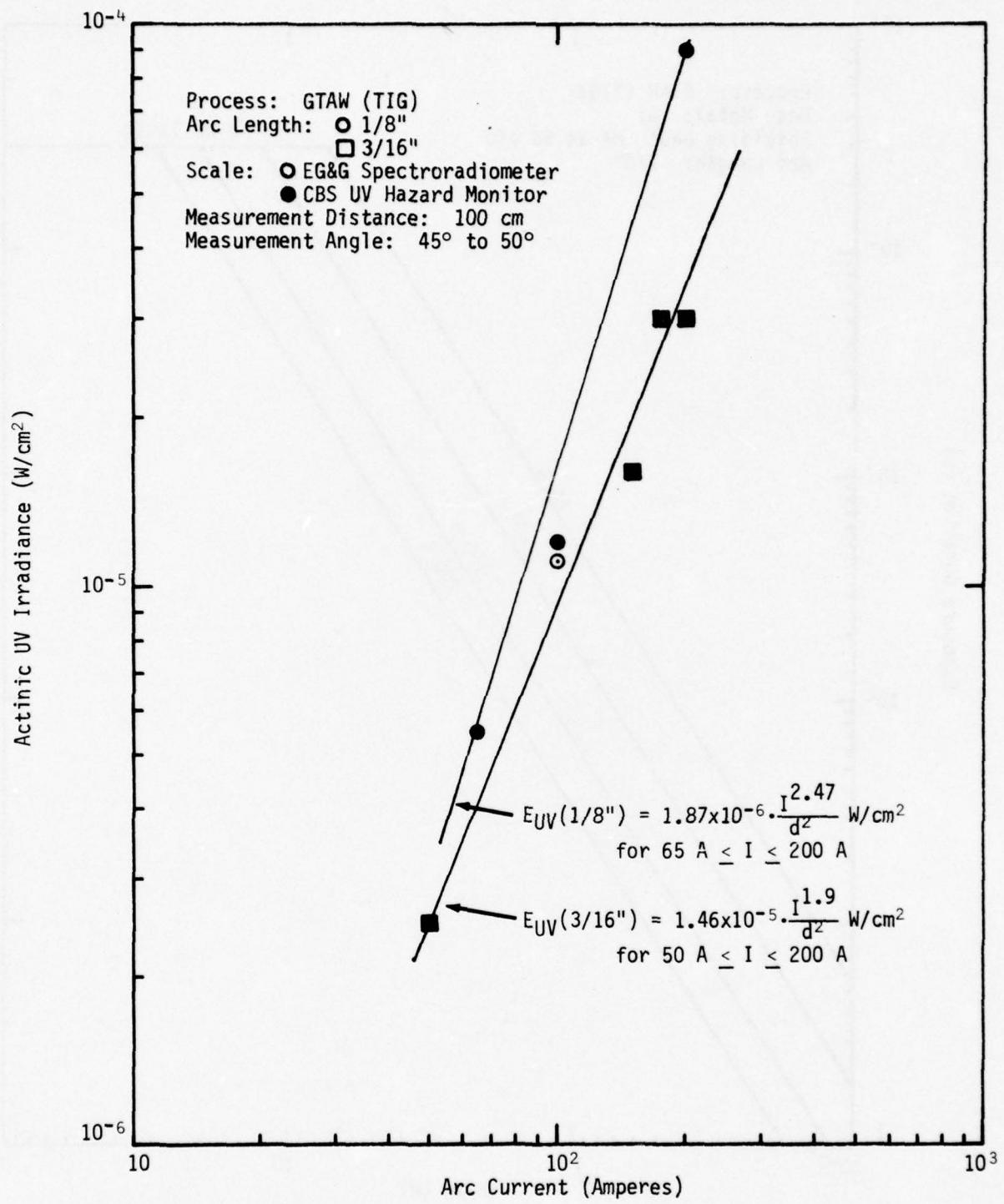


Figure 21. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 34 to 39. The irradiance decreases with arc length.

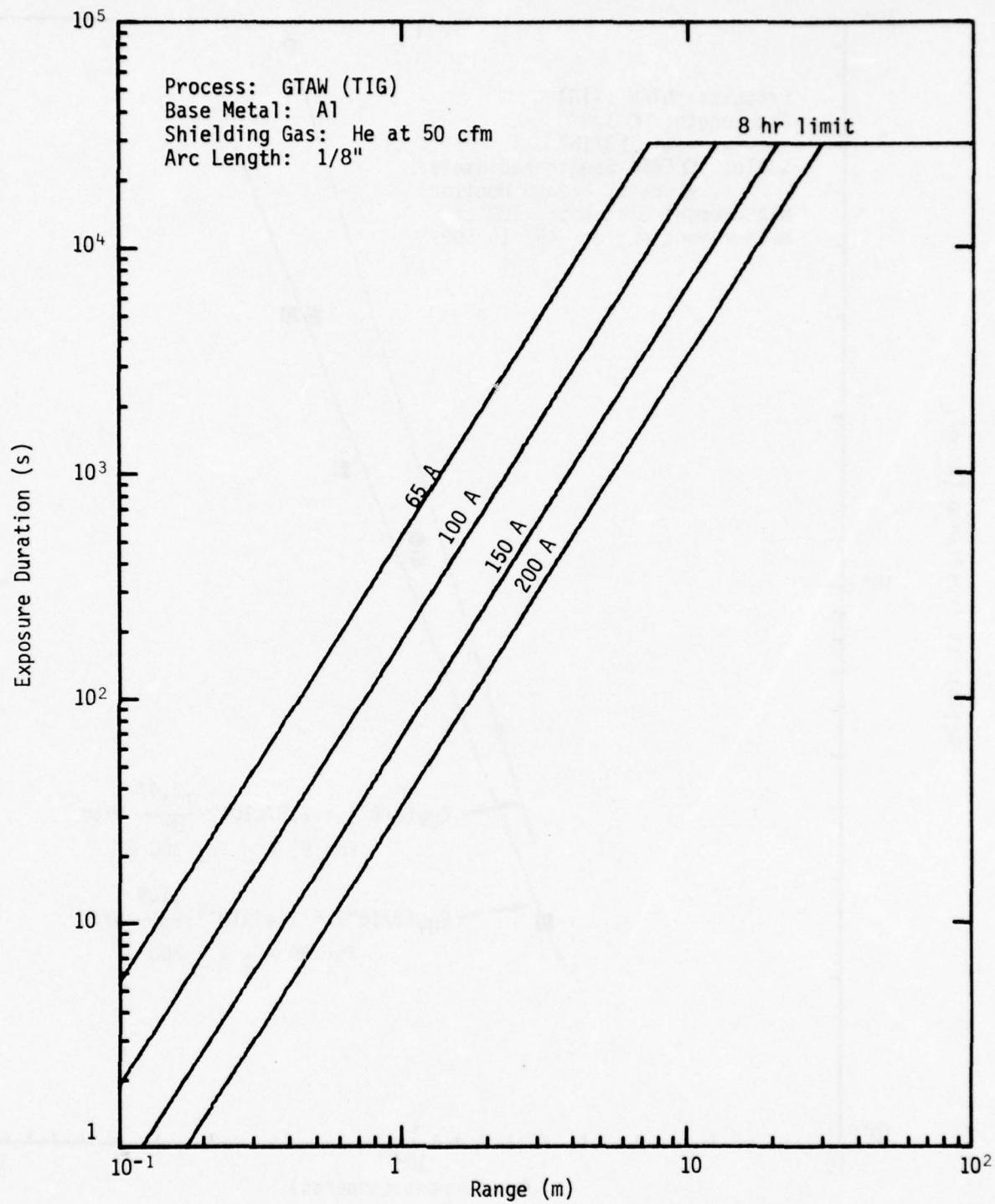


Figure 22. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 34 to 39.

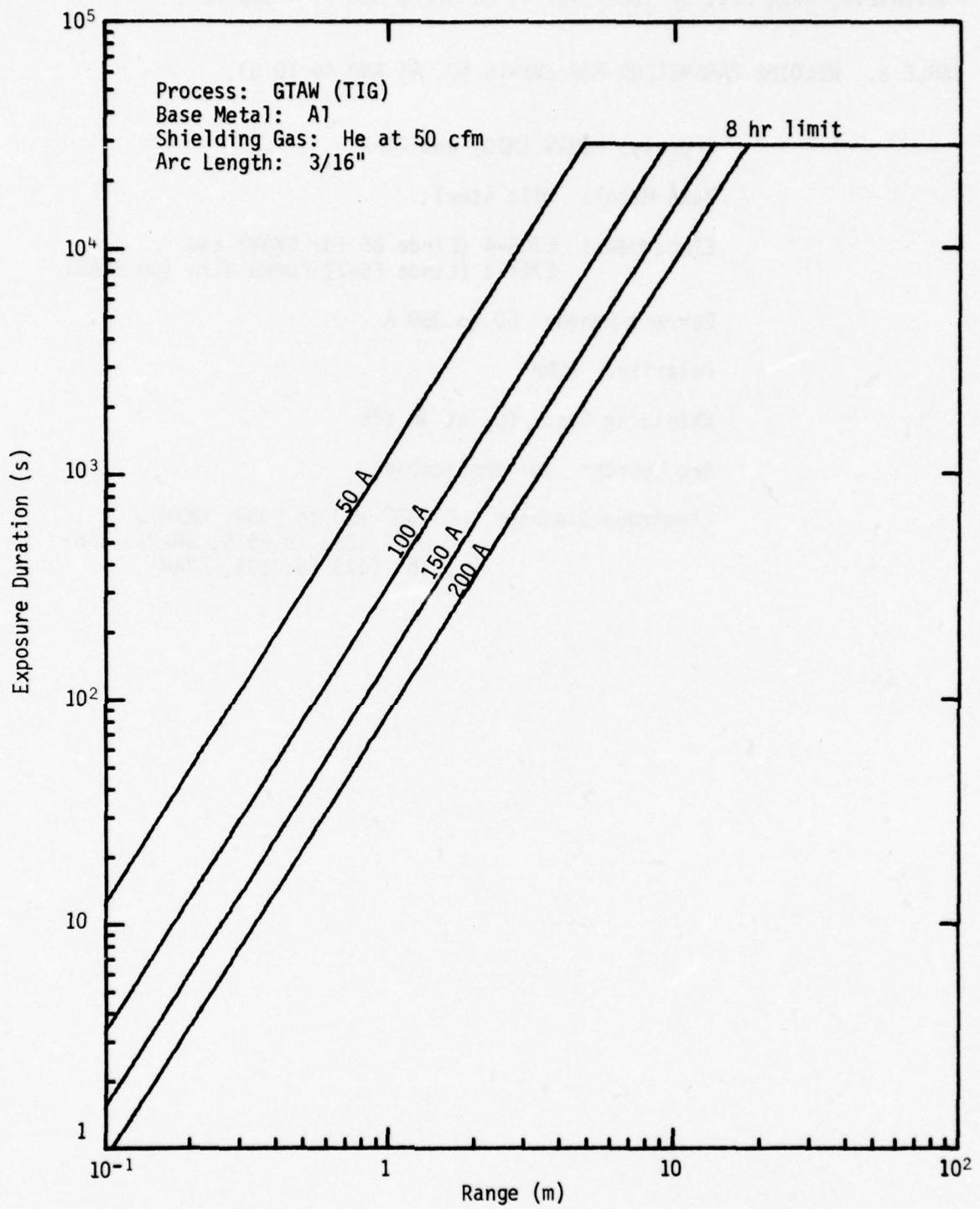


Figure 23. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 34 to 39.

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TABLE 8. WELDING PARAMETERS FOR EVENTS 40, 41 AND 49 TO 53.

Process: GMAW (MIG) and FCAW

Base Metal: mild steel

Electrodes: E70S-4 (Linde 85 for GMAW) and  
E70T-1 (Linde FC-72 Cored Wire for FCAW)

Current Range: 90 to 350 A

Polarity: DCRP

Shielding Gas: CO<sub>2</sub> at 40 cfm

Arc Length: not applicable

Electrode Diameter: 0.035" (90 to 200A, GMAW),  
0.045" (250 to 350A, GMAW), and  
1/16" (175 to 350A, FCAW)

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Process: GMAW  
Arc Current: 90A

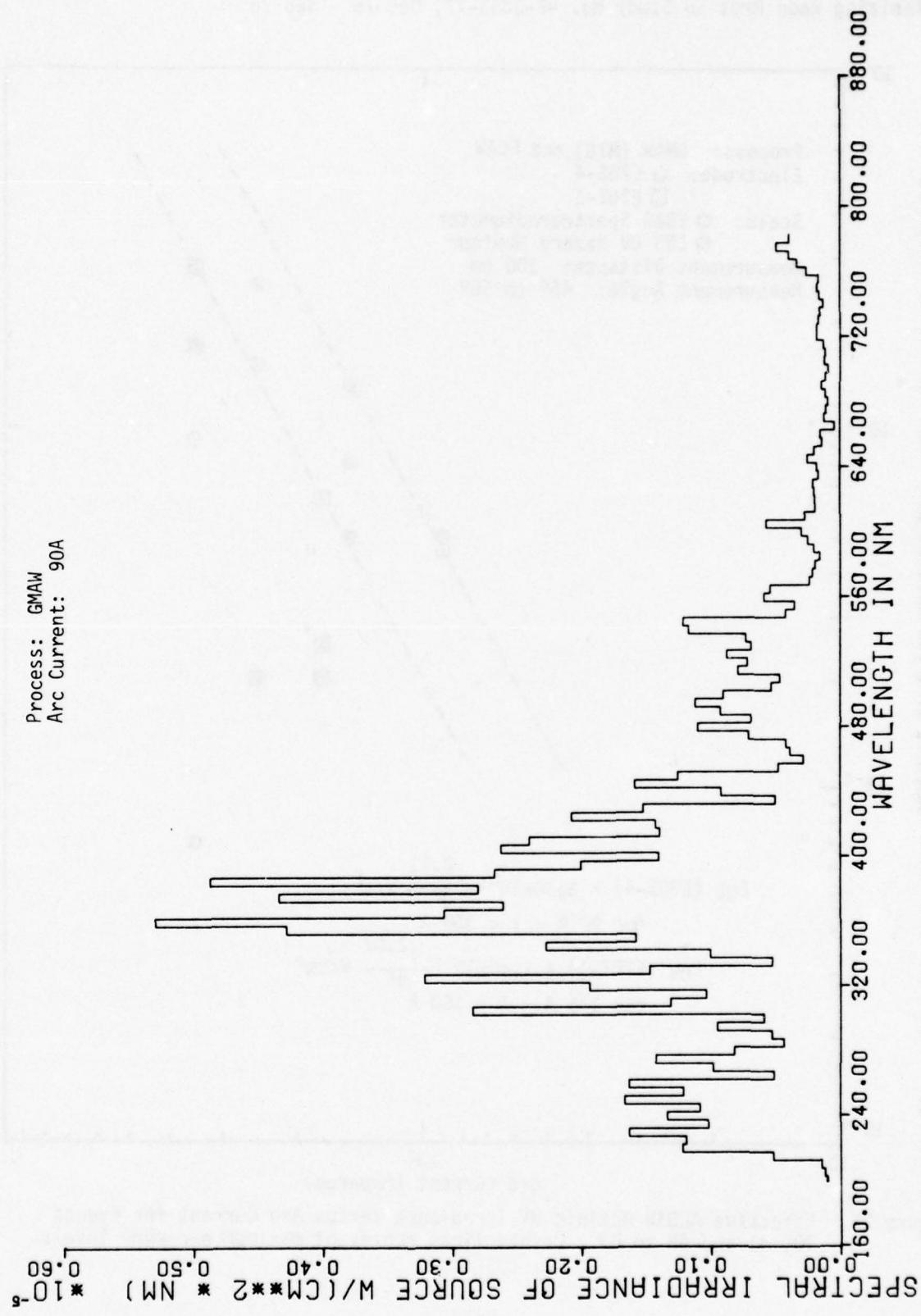


FIGURE 24 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 40

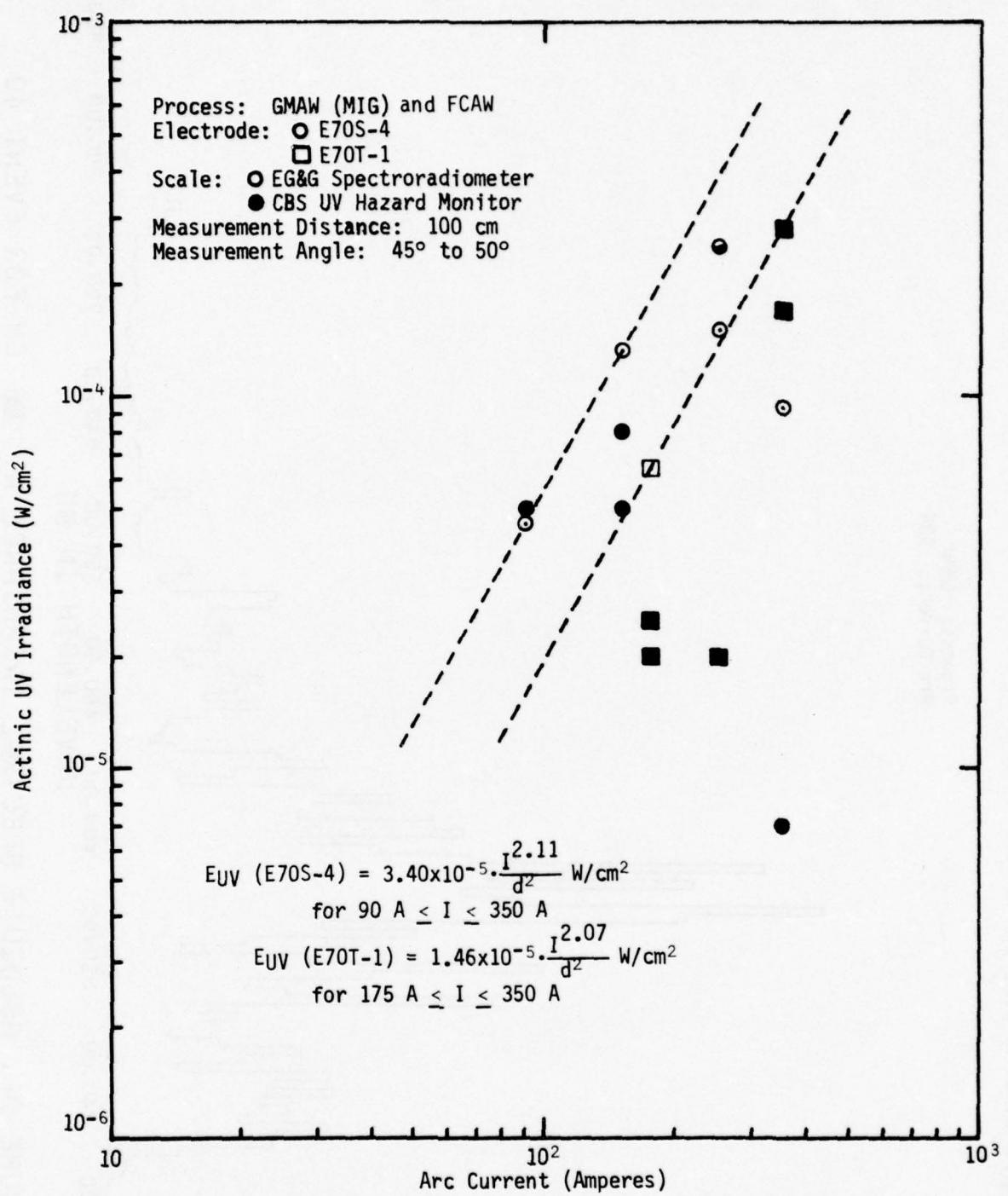


Figure 25. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 40, 41 and 49 to 53. Dashed lines represent maximum exposure levels.

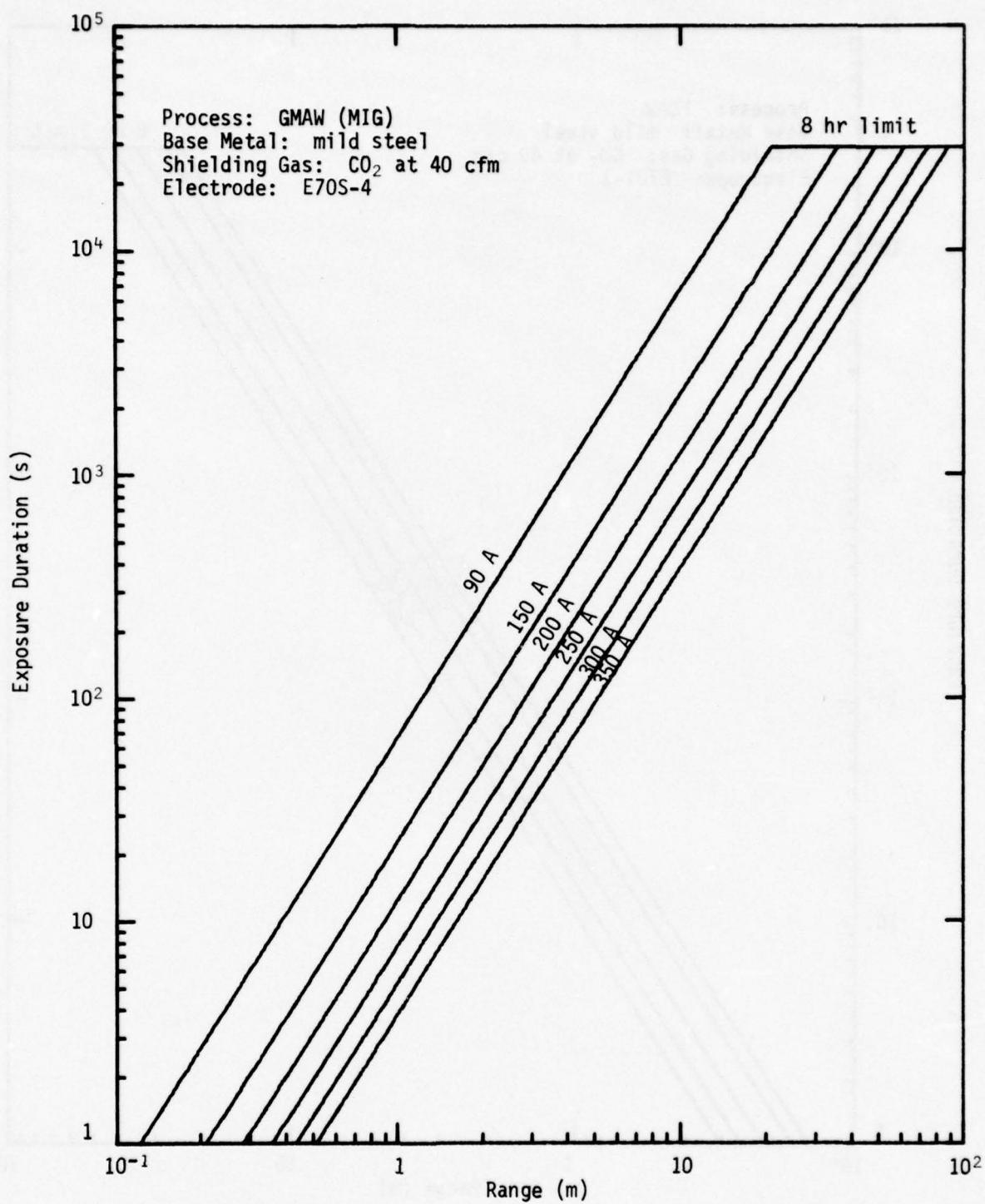


Figure 26. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 40, 41 and 49 to 53.

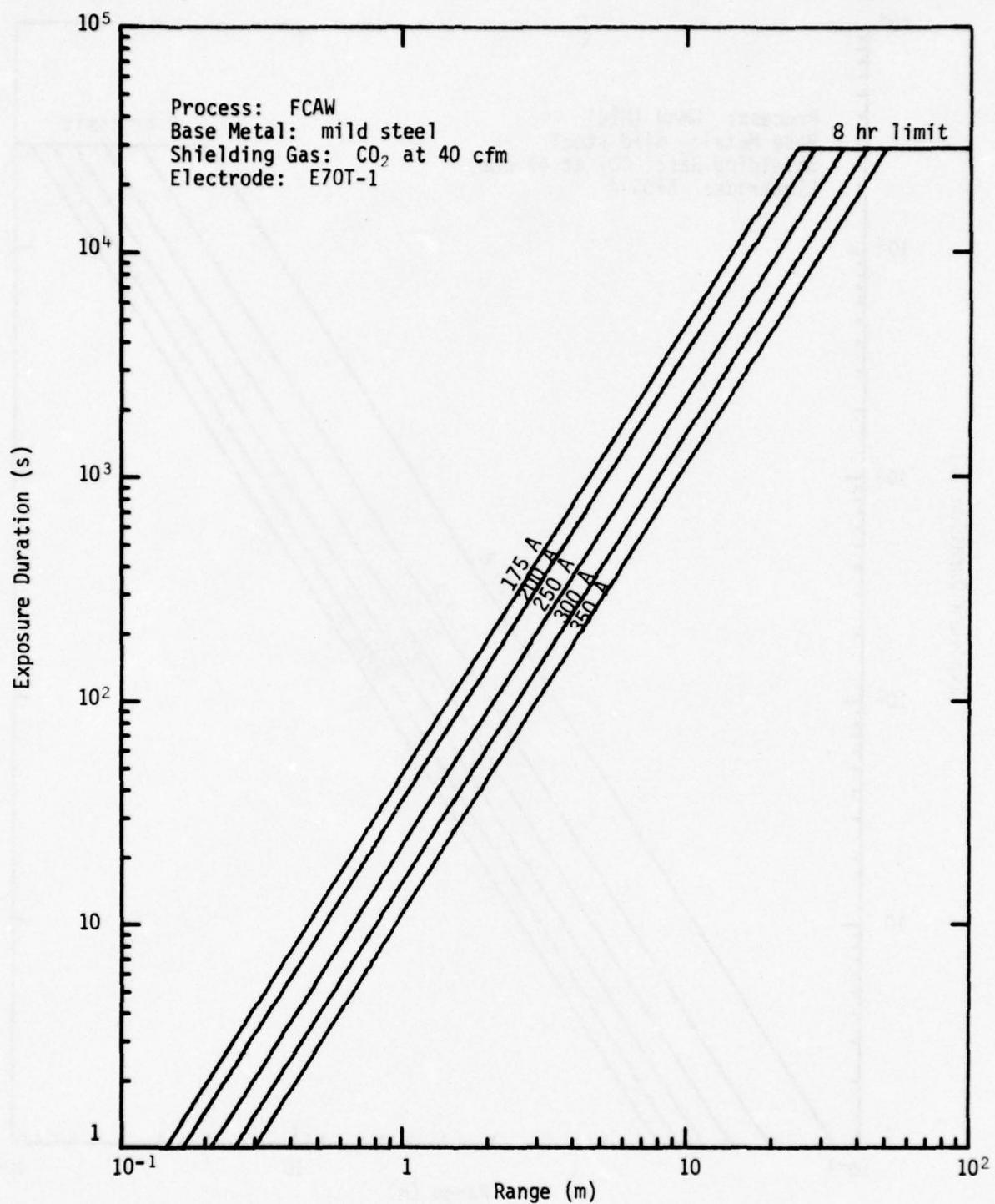


Figure 27. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 40, 41 and 49 to 53.

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TABLE 9. WELDING PARAMETERS FOR EVENTS 42 TO 48.

Process: GMAW (MIG)

Base Metal: mild steel

Electrode: E70S-4 (Linde 85)

Current Range: 150 to 350 A

Polarity: DCRP

Shielding Gas: 5% O<sub>2</sub> and 95% Ar at 50 cfm

Arc Lengths: 1/4" and 3/8"

Electrode Diameter: 0.035" (150 to 200A) and  
0.045" (250 to 350A)

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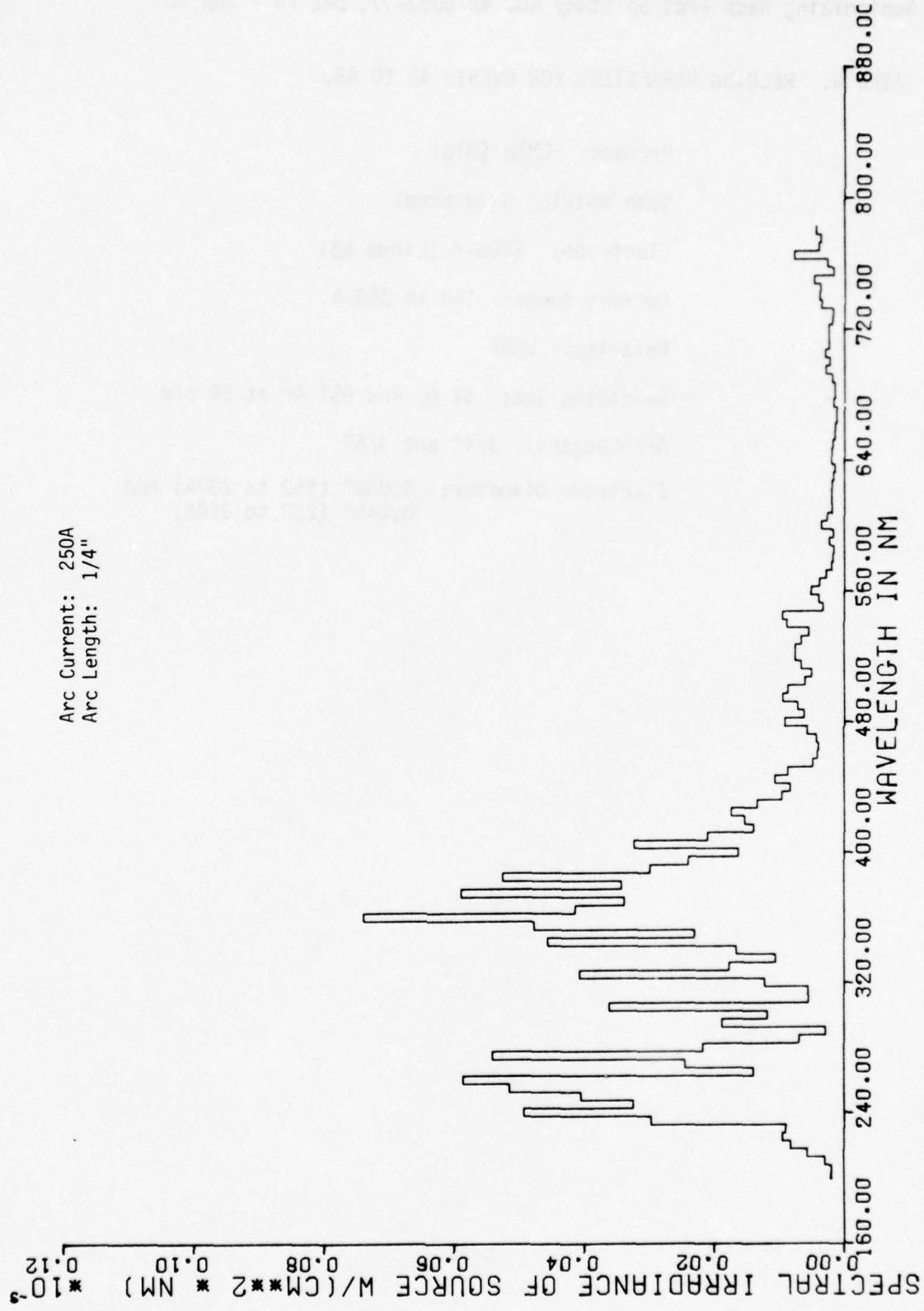


FIGURE 28 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 45

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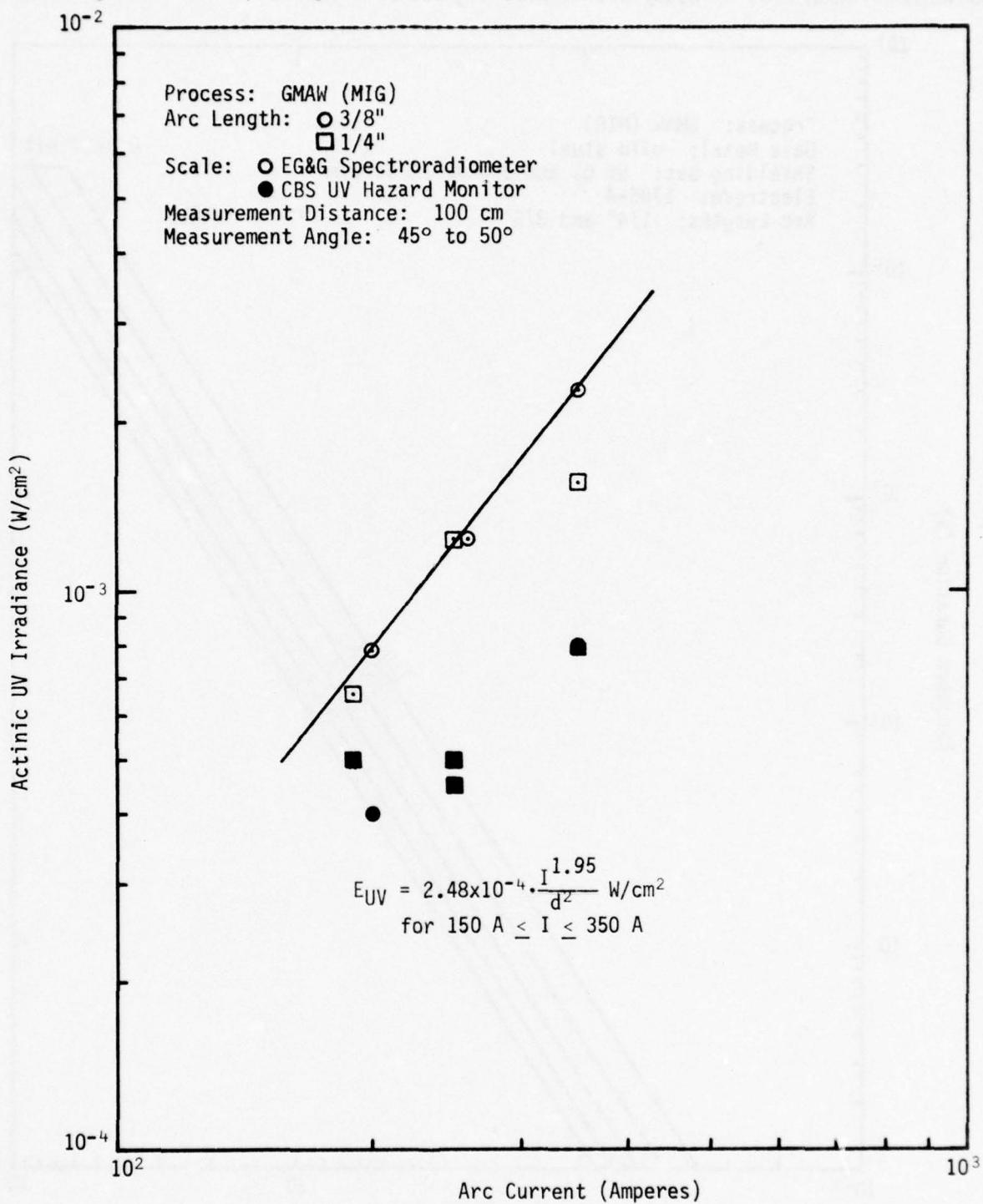


Figure 29. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 42 to 48.

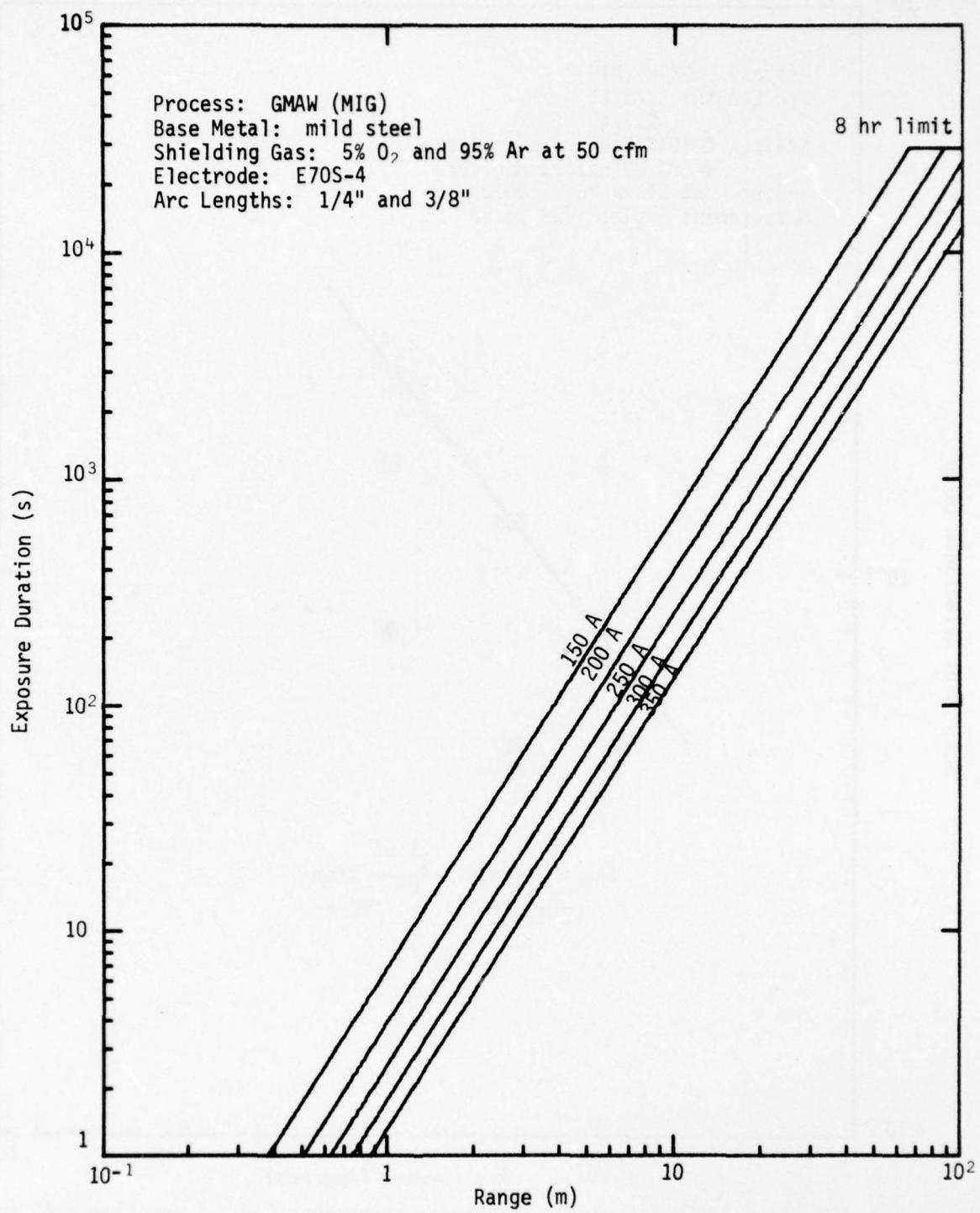


Figure 30. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 42 to 48.

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TABLE 10. WELDING PARAMETERS FOR EVENTS 54, 55, 58 AND 59.

Process: GMAW (MIG)

Base Metal: Al

Electrode: E5356

Current Range: 130 to 300 A

Polarity: DCRP

Shielding Gas: Ar at 50 cfm

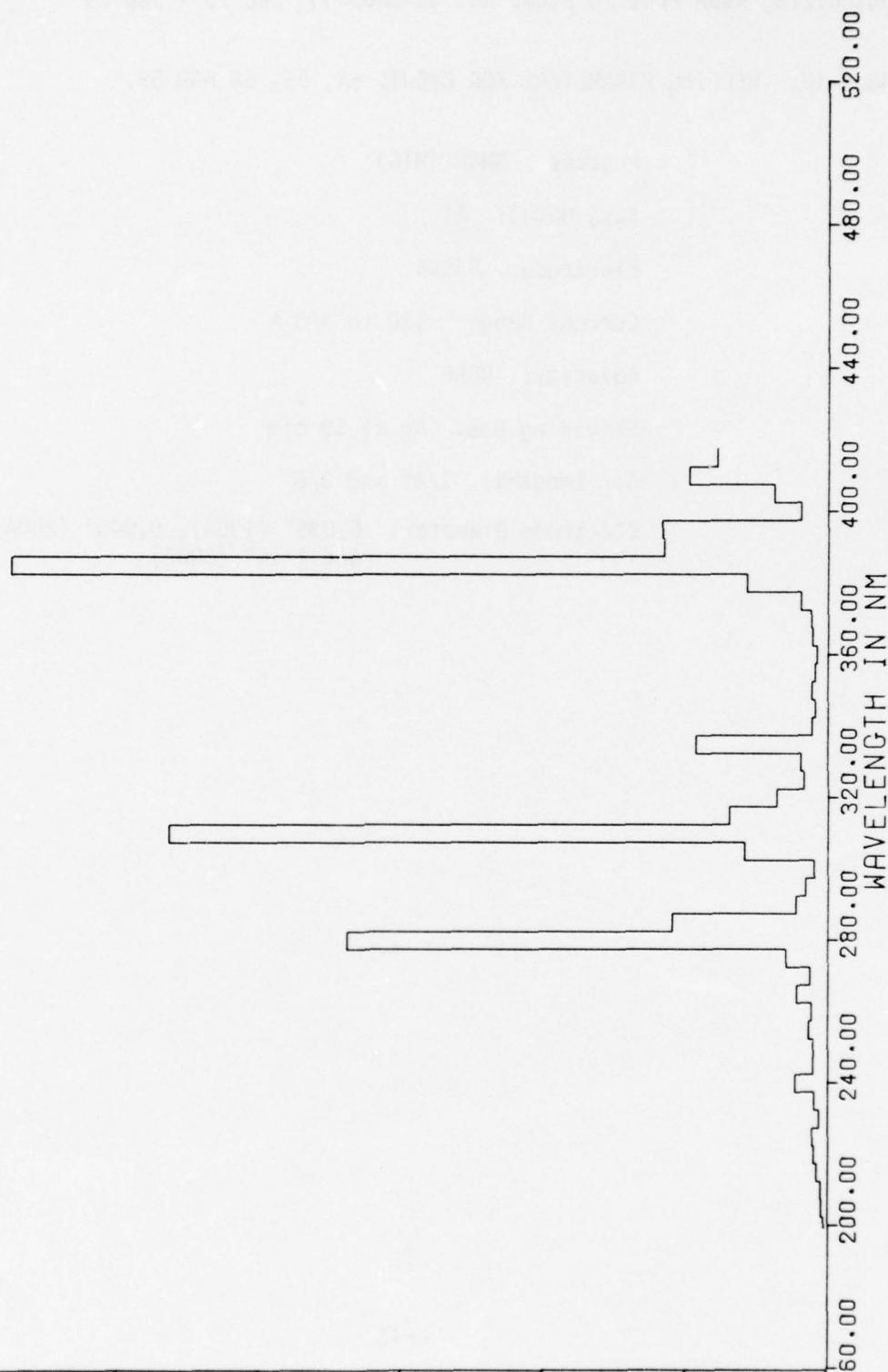
Arc Lengths: 1/4" and 3/8"

Electrode Diameter: 0.035" (130A), 0.045" (200A),  
and 1/16" (300A)

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SPECTRAL IRRADIANCE OF SOURCE M/(CM\*\*2 \* NM) \*10<sup>-3</sup>

Arc Current: 200A  
Arc Length: 1/4"



C-42

FIGURE 31 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 58

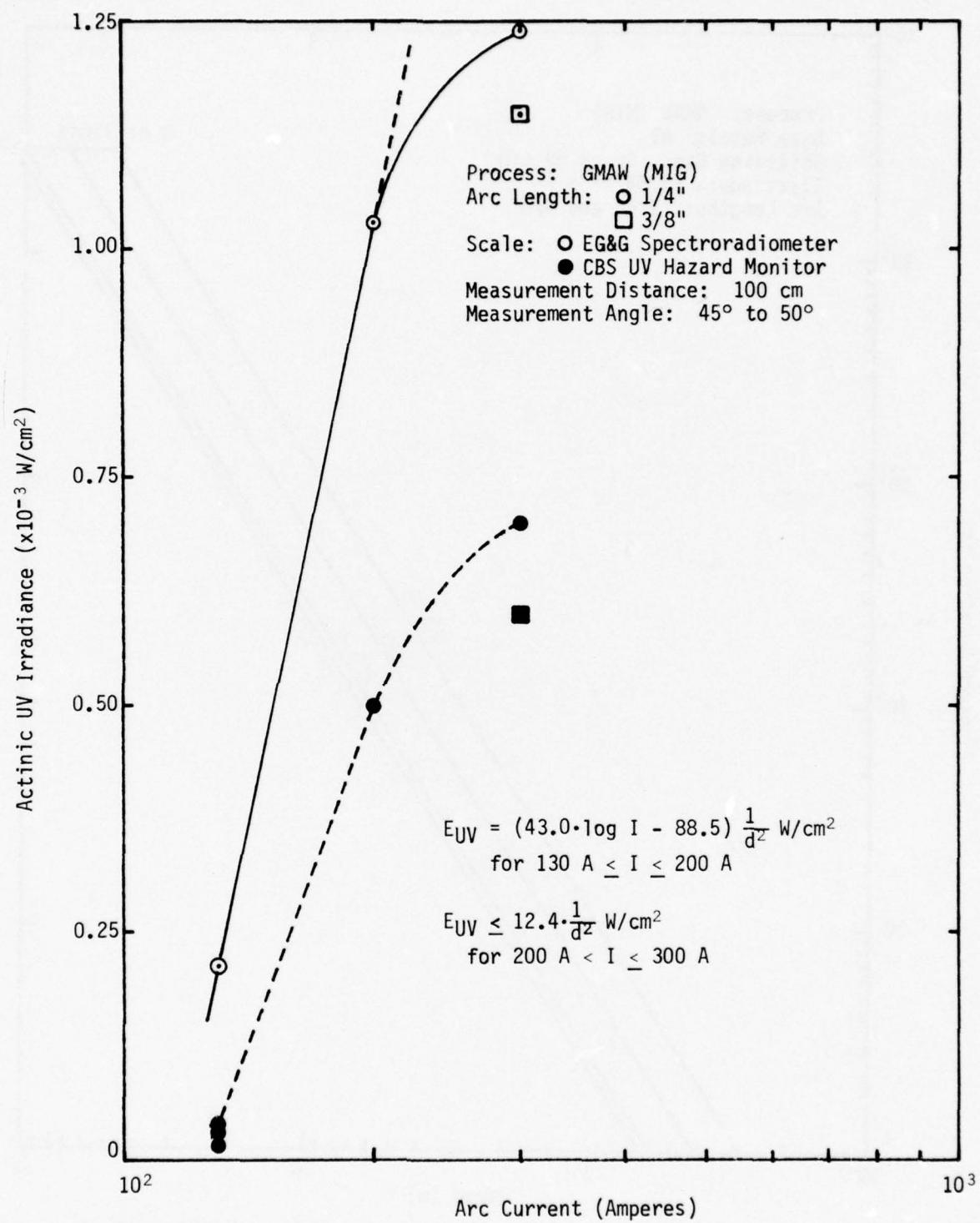


Figure 32. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 54, 55, 58 and 59. The irradiance begins to saturate at 200 amperes. The difference in the two curves is attributed to instrumentation differences.

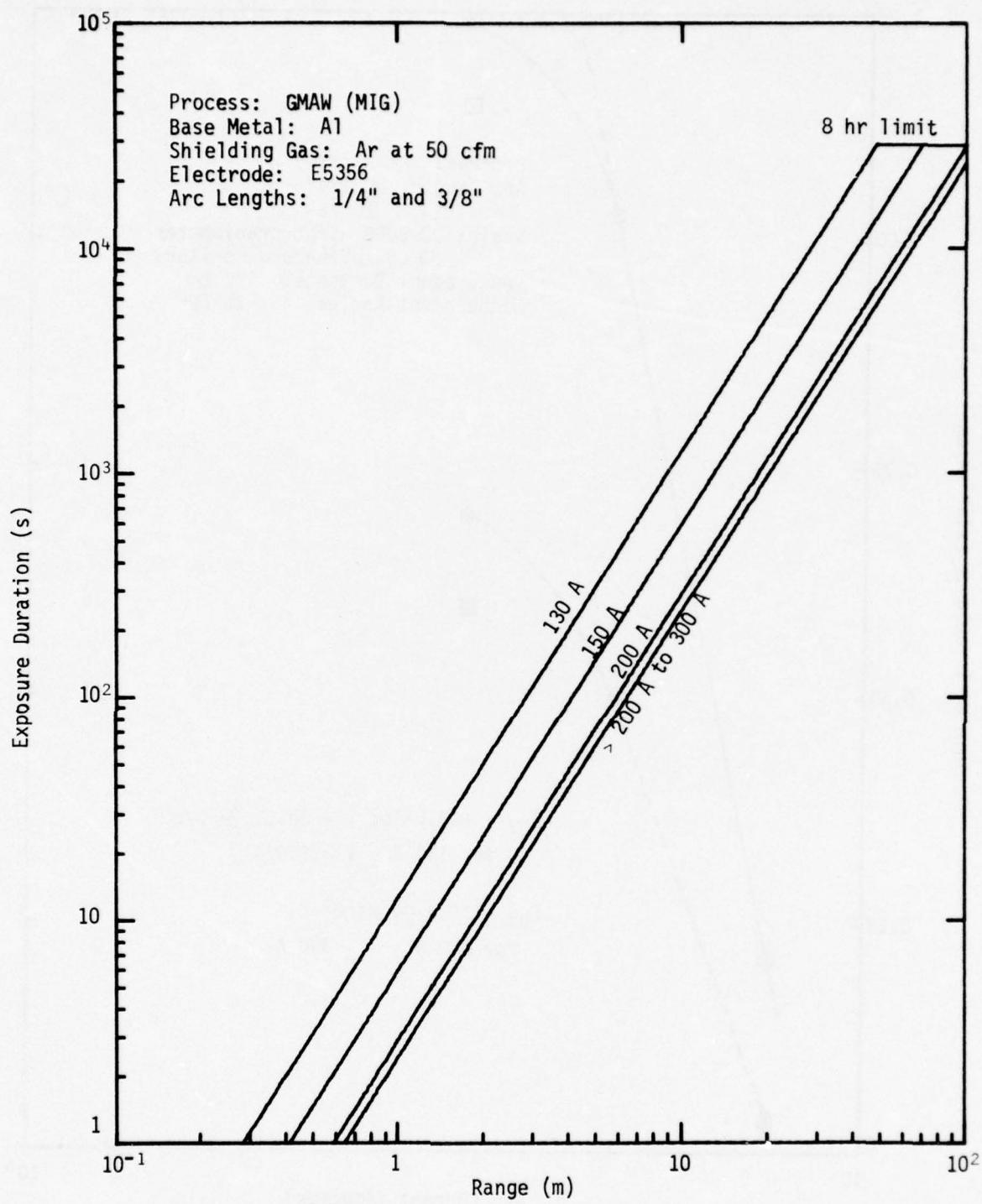


Figure 33. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 54, 55, 58 and 59.

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TABLE 11. WELDING PARAMETERS FOR EVENTS 56, 57 AND 60

Process: GMAW (MIG)

Base Metal: Al

Electrode: E5356

Current Range: 125 to 300 A

Polarity: DCRP

Shielding Gas: He at 75 cfm

Arc Length: 1/4"

Electrode Diameter: 0.035" (125A), 0.045" (200A),  
and 1/16" (300A)

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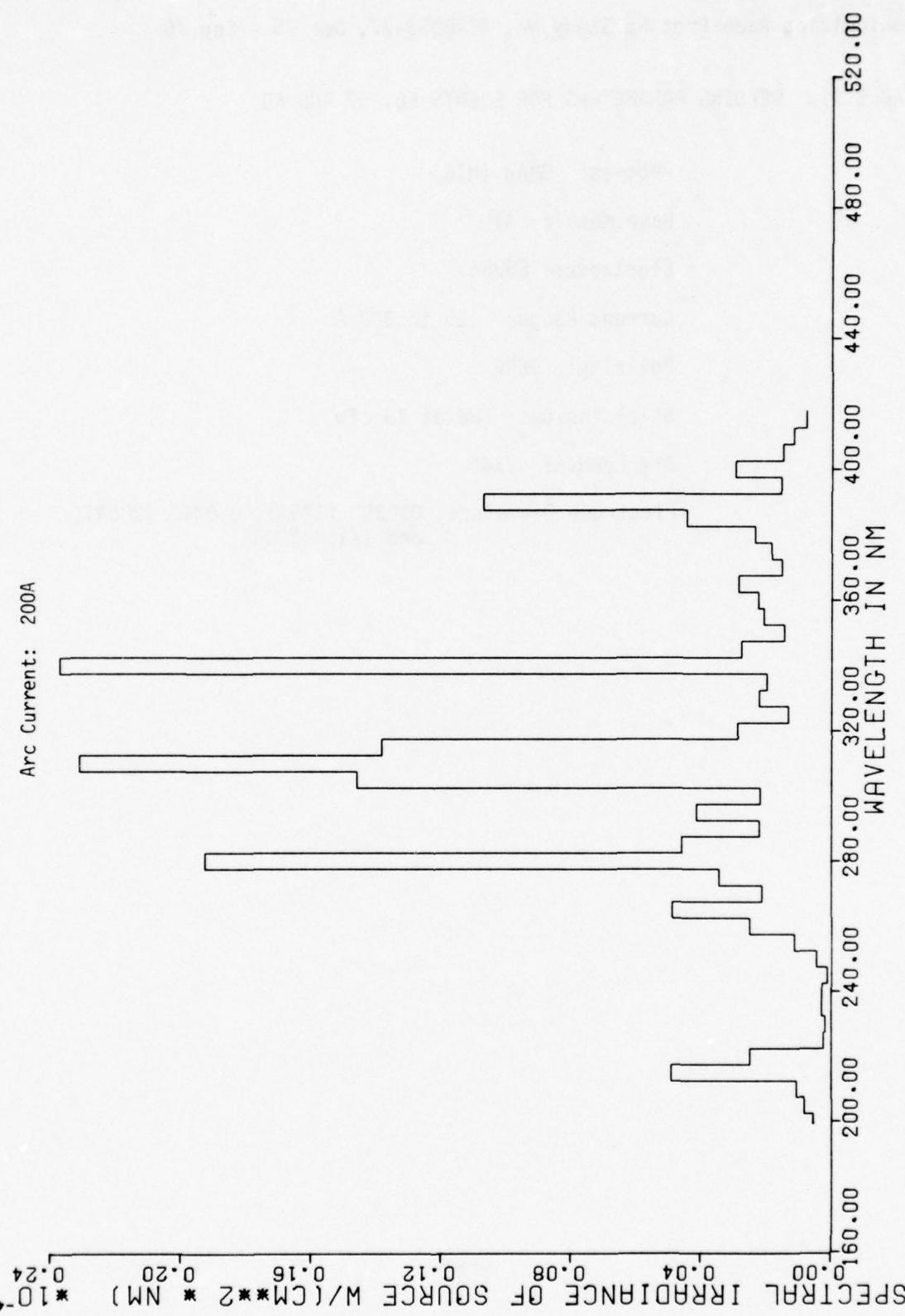


FIGURE 34. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 57

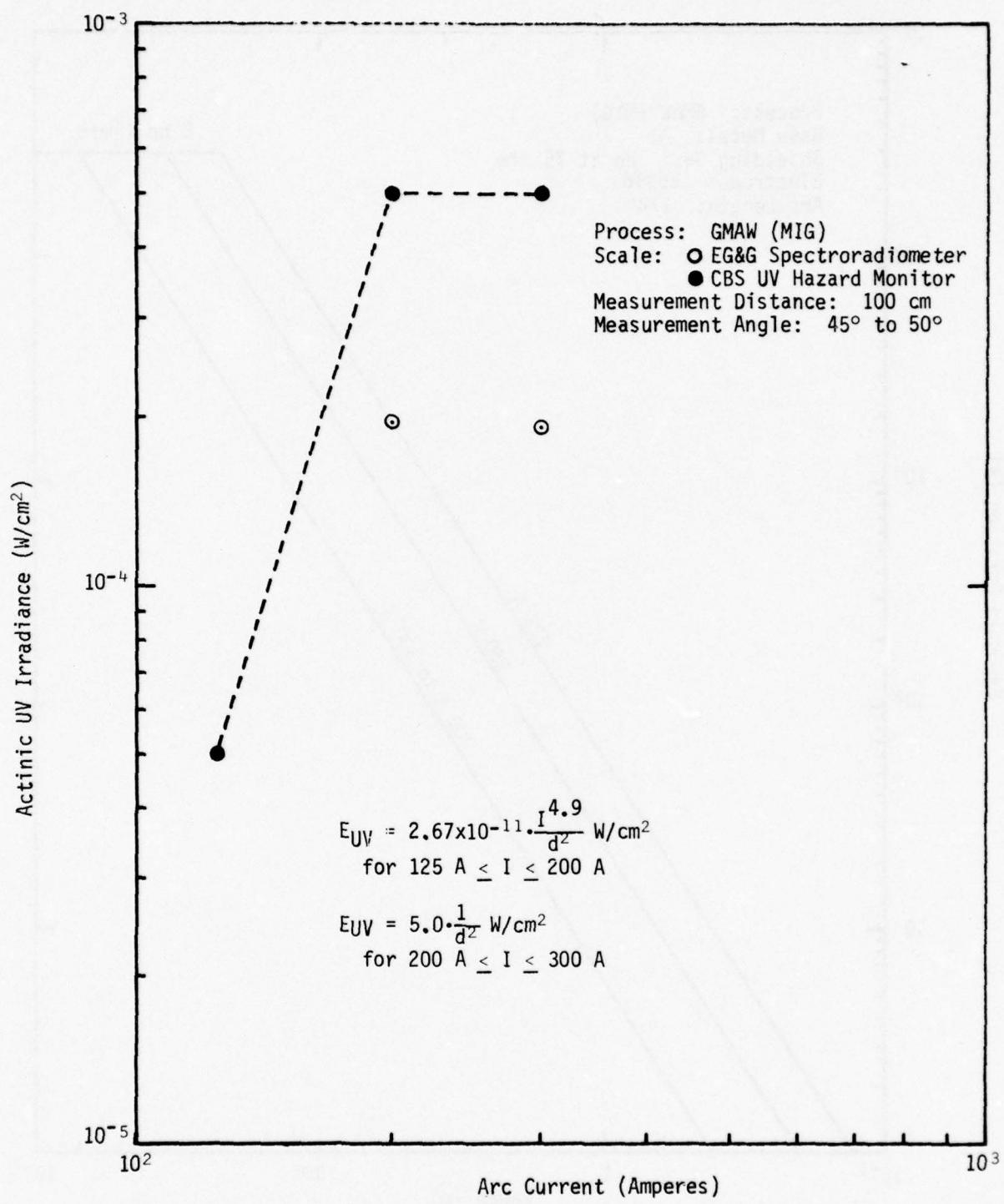


Figure 35. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 56, 57 and 60. The irradiance appears to saturate at 200 amperes.

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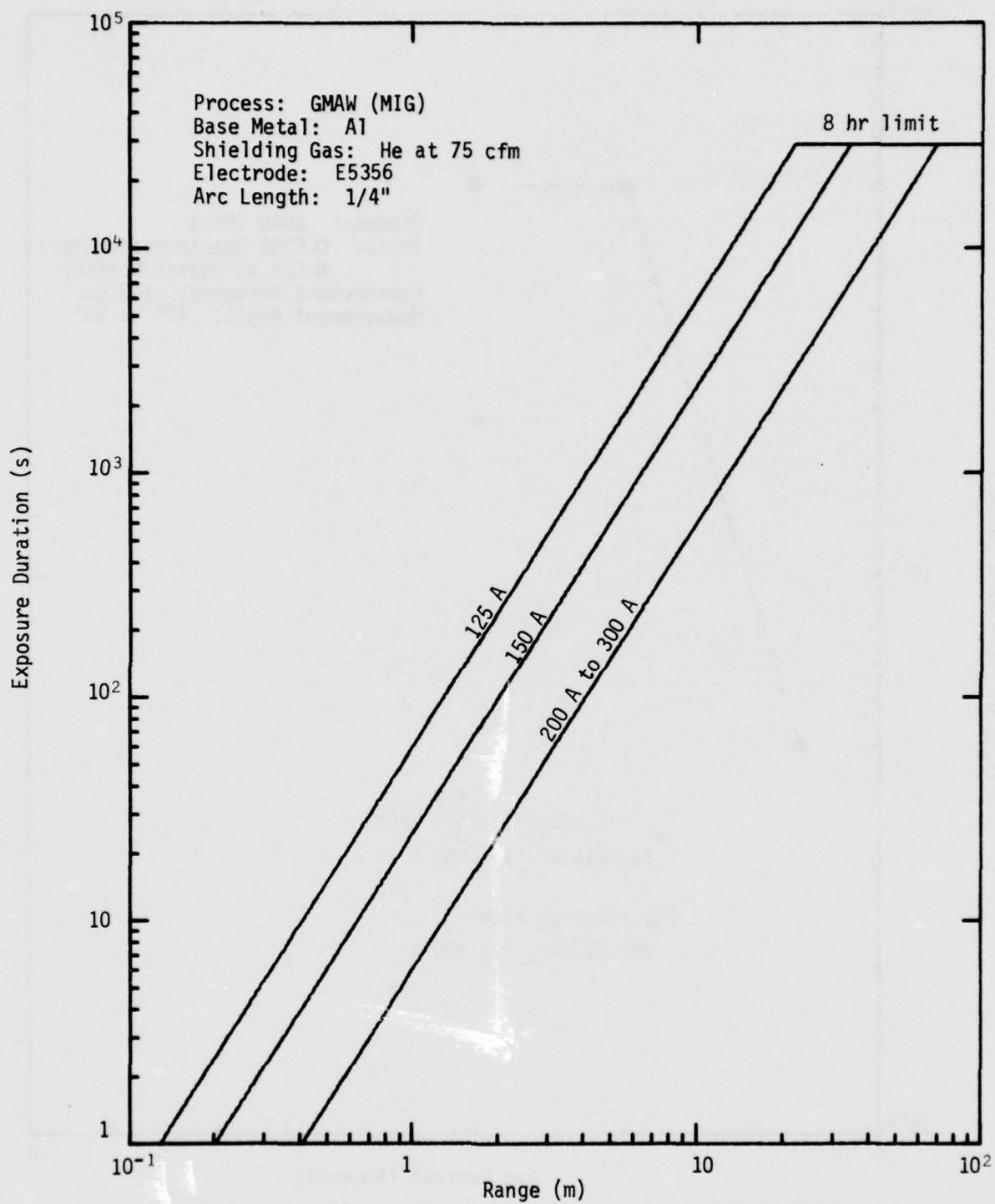


Figure 36. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 56, 57 and 60.

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TABLE 12. WELDING PARAMETERS FOR EVENTS 73 TO 81.

Process: PAC Dry Cutting

Base Metal: mild steel (1" thick)

Torch: PT-7

Current Range: 400 to 1000 A

Shielding Gas: 65% Ar and 35% H (175 cfh for  $I = 400$  A,  
200 cfh for  $500 \text{ A} < I \leq 750$  A, and 300  
cfh for  $I = 1000$  A)

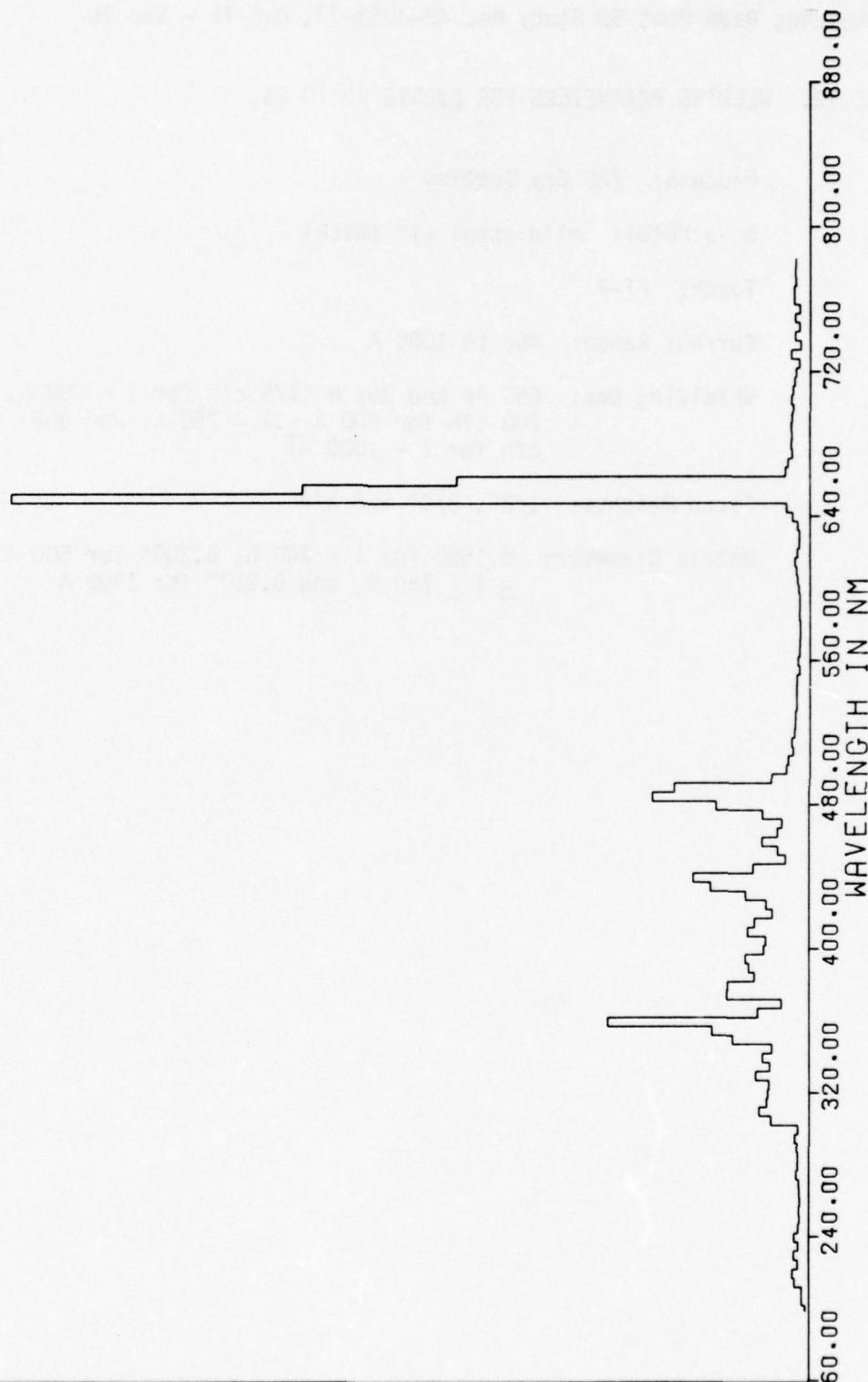
Torch Heights: 1/2", 3/8" and 3/4"

Nozzle Diameter: 0.156" for  $I = 400$  A, 0.200" for  $500 \text{ A} \leq I \leq 750$  A, and 0.230" for 1000 A

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SPECTRAL IRRADIANCE OF SOURCE M/(CM\*\*2 \* NM) \*10^-4

Plasma Arc Current: 400A  
Torch Height: 3/8"



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FIGURE 37 . ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 73

Nonionizing Radn Prot Sp Study No. 42-0053-77, Dec 75 - Sep 76

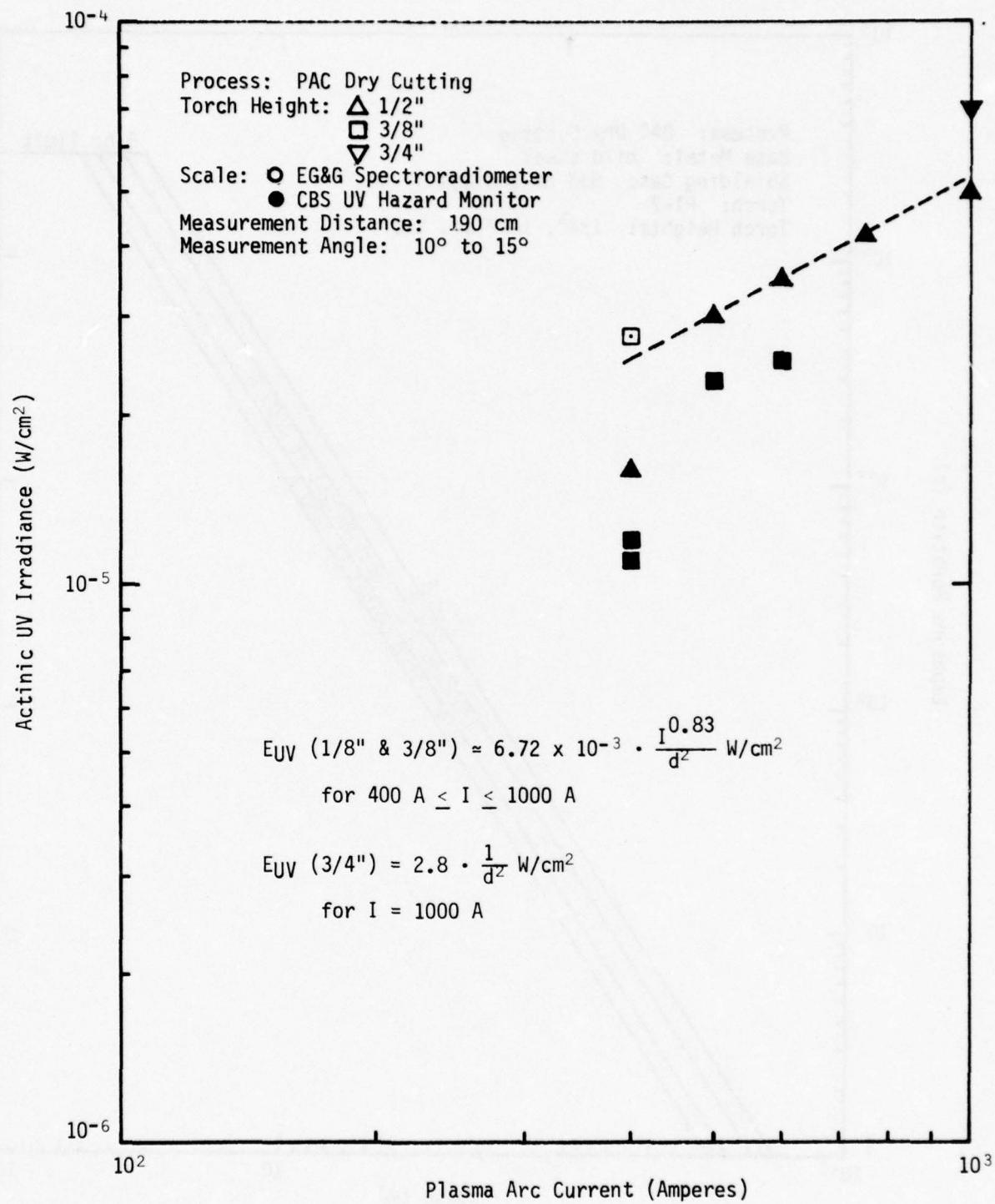


Figure 38. Effective ACGIH Actinic UV Irradiance Versus Plasma Arc Current for Events 73 to 81.

Nonionizing Radn Prot Sp Study No. 42-0053-77, Dec 75 - Sep 76

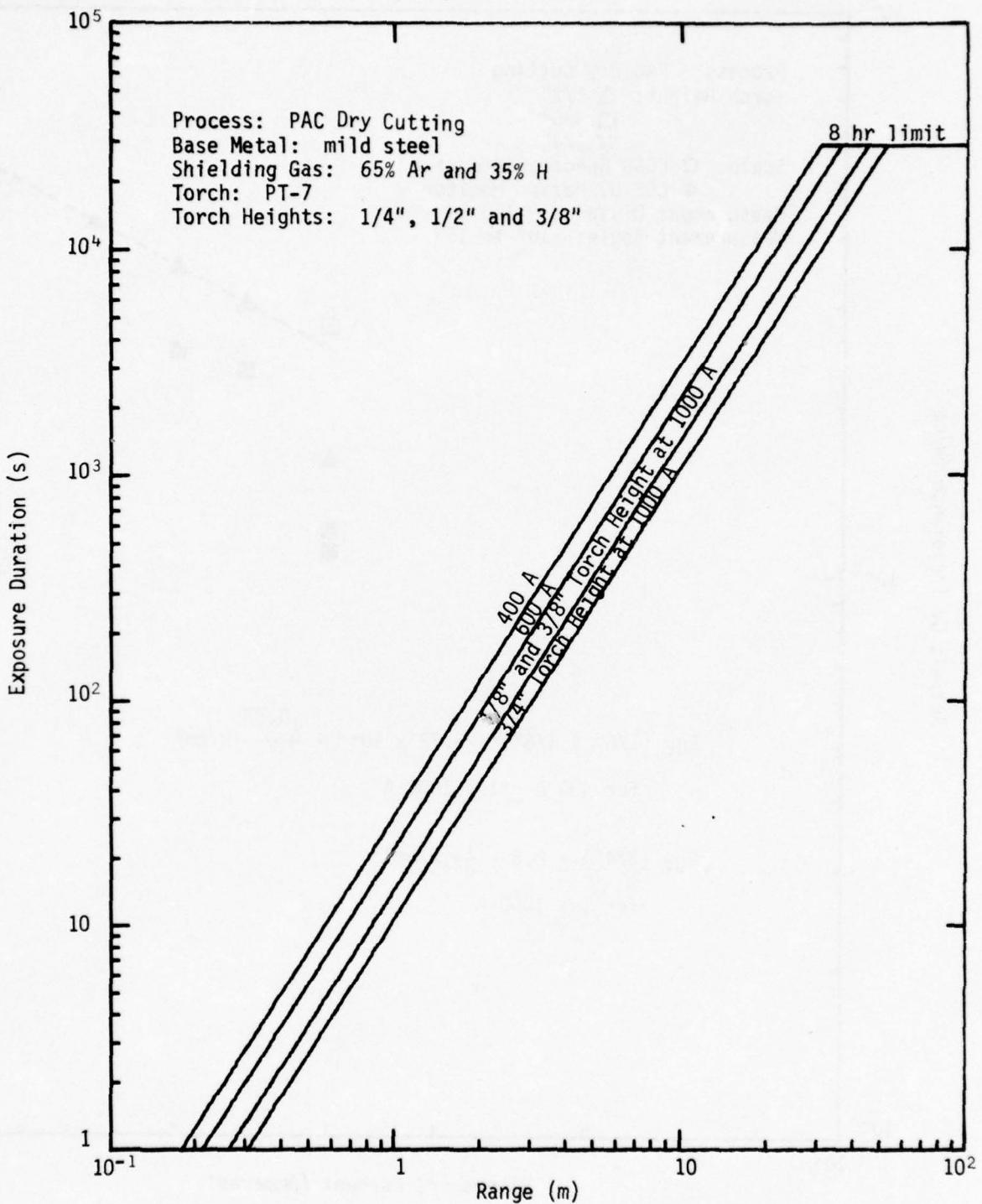


Figure 39. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Plasma Arc Operating at Various Currents for Events 73 to 81.

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TABLE 13. WELDING PARAMETERS FOR EVENTS 61 TO 72.

Process: PAC with water injection

Base Metal: mild steel (5/8" thick for  
 $I \leq 400$  A and 1" for  $I \geq 600$  A)

Torch: PT-15

Current Range: 300 to 750 A

Shielding Gas: N<sub>2</sub> (140 cfh for  $I < 400$  A,  
180 cfh for  $500 \leq I < 600$  A,  
and 220 cfh for  $I = 750$  A)

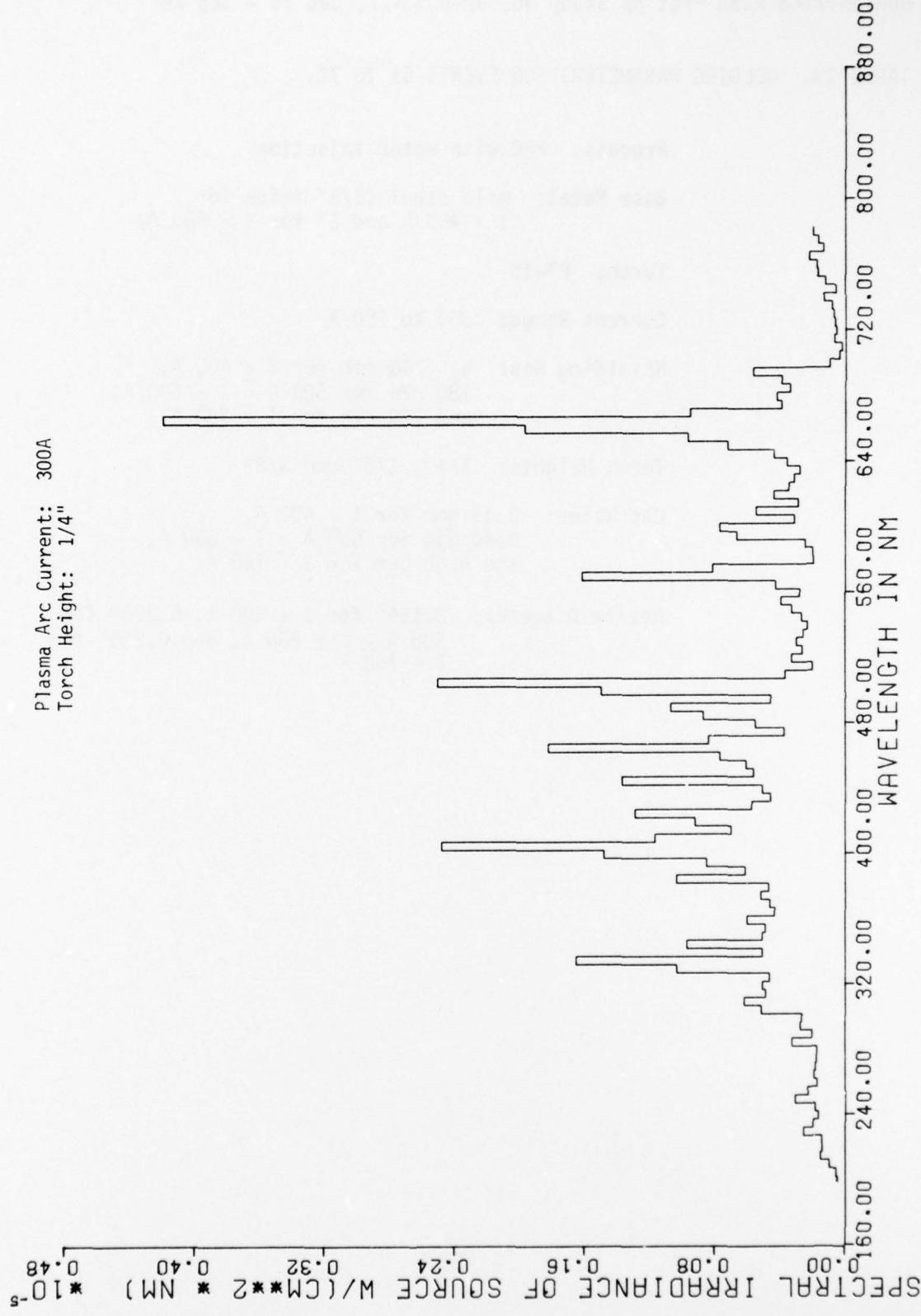
Torch Heights: 1/4", 1/2" and 3/8"

Cut Water: 0.33 gpm for  $I < 400$  A,  
0.40 gpm for  $500 \leq I < 600$  A,  
and 0.48 gpm for  $I = 750$  A

Nozzle Diameter: 0.156" for  $I < 400$  A, 0.200" for  
 $500 \leq I \leq 600$  A, and 0.230" for  
 $I = 750$  A

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Plasma Arc Current: 300A  
Torch Height: 1/4"



C-54

FIGURE 40 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 61

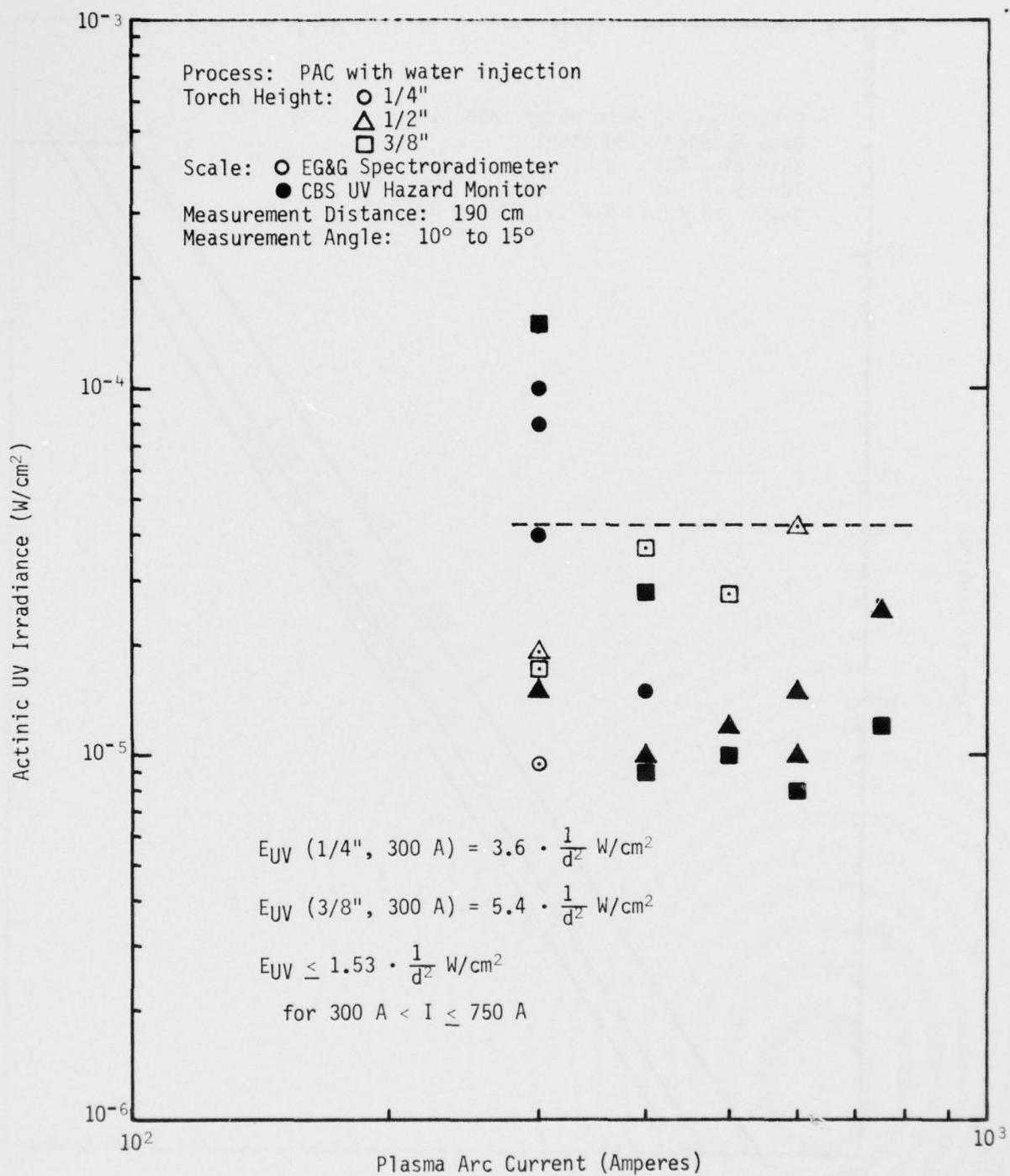


Figure 41. Effective ACGIH Actinic UV Irradiance Versus Plasma Arc Current for Events 61 to 72. Data varies significantly but the irradiance appears to be saturated.

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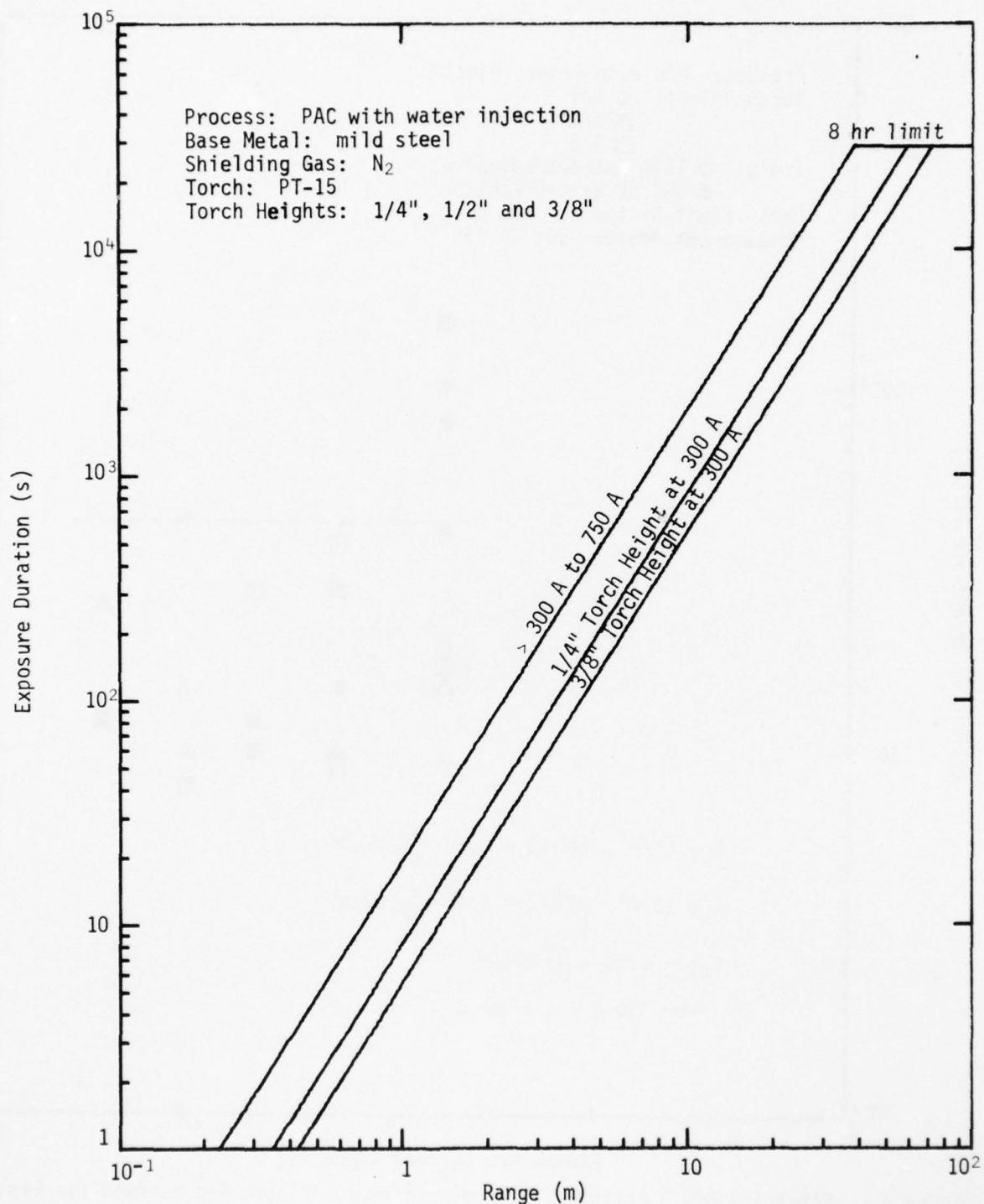


Figure 42. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Plasma Arc Operating at Various Currents for Events 61 to 72.

Nonionizing Radn Prot Sp Study No. 42-0053-77, Dec 75 - Sep 76

TABLE 14. WELDING PARAMETERS FOR EVENTS 82 TO 86.

Process: PAC with water injection and water muffler

Base Metal: mild steel (1" thick)

Torch: PT-15

Current Range: 400 to 600 A

Shielding Gas: N<sub>2</sub> (140 cfh for I = 400 A and 180 cfh for I = 600 A)

Torch Heights: 1/4", 1/2" and 3/8"

Cut Water: 0.33 gpm for I = 400 A and 0.40 gpm for I = 600 A

Nozzle Diameter: 0.156" for I = 400 A and 0.200" for I = 600 A

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Plasma Arc Current: 400A  
Torch Height: 3/8"

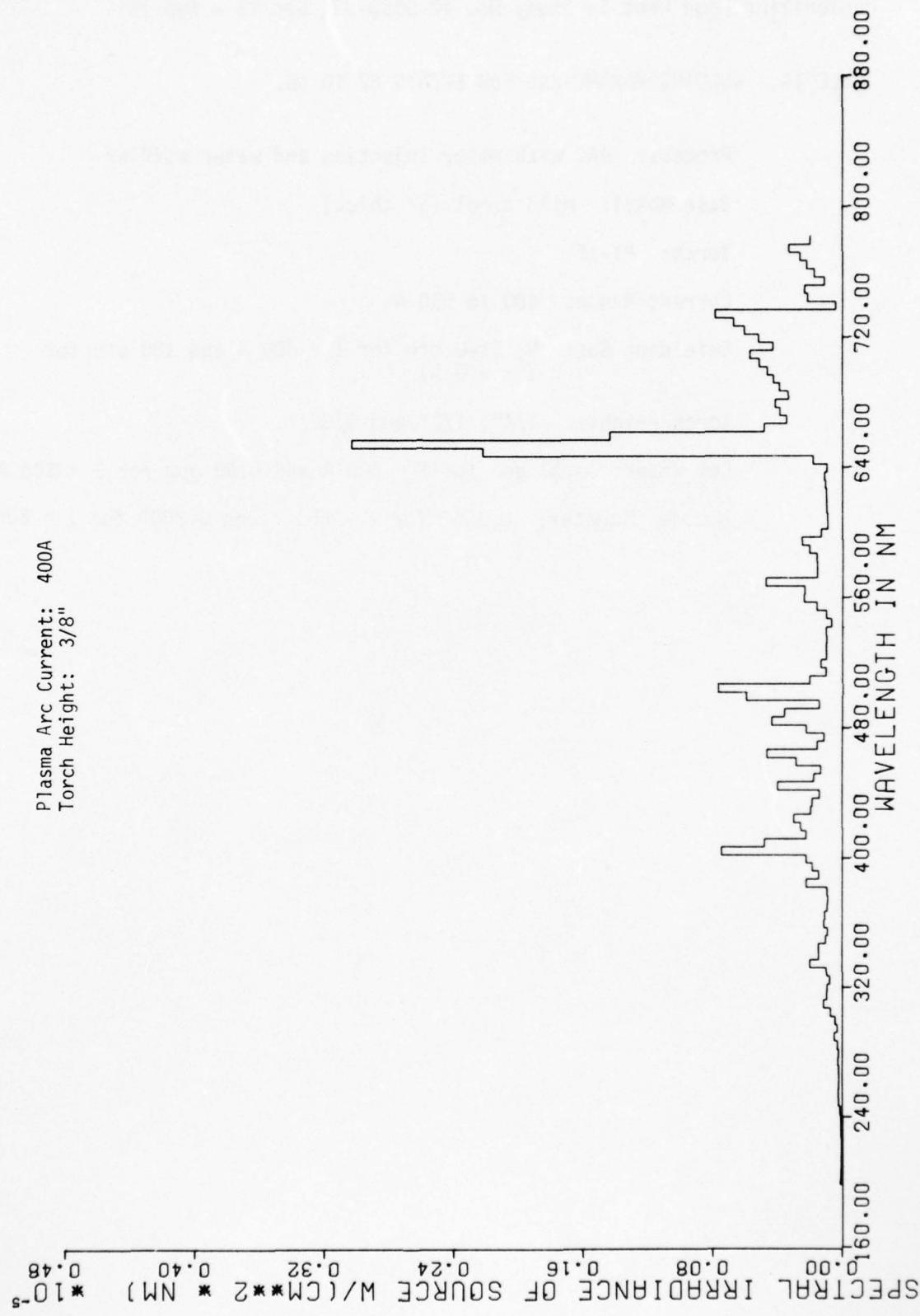


FIGURE 43 . ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 83

Nonionizing Radn Prot Sp Study No. 42-0053-77, Dec 75 - Sep 76

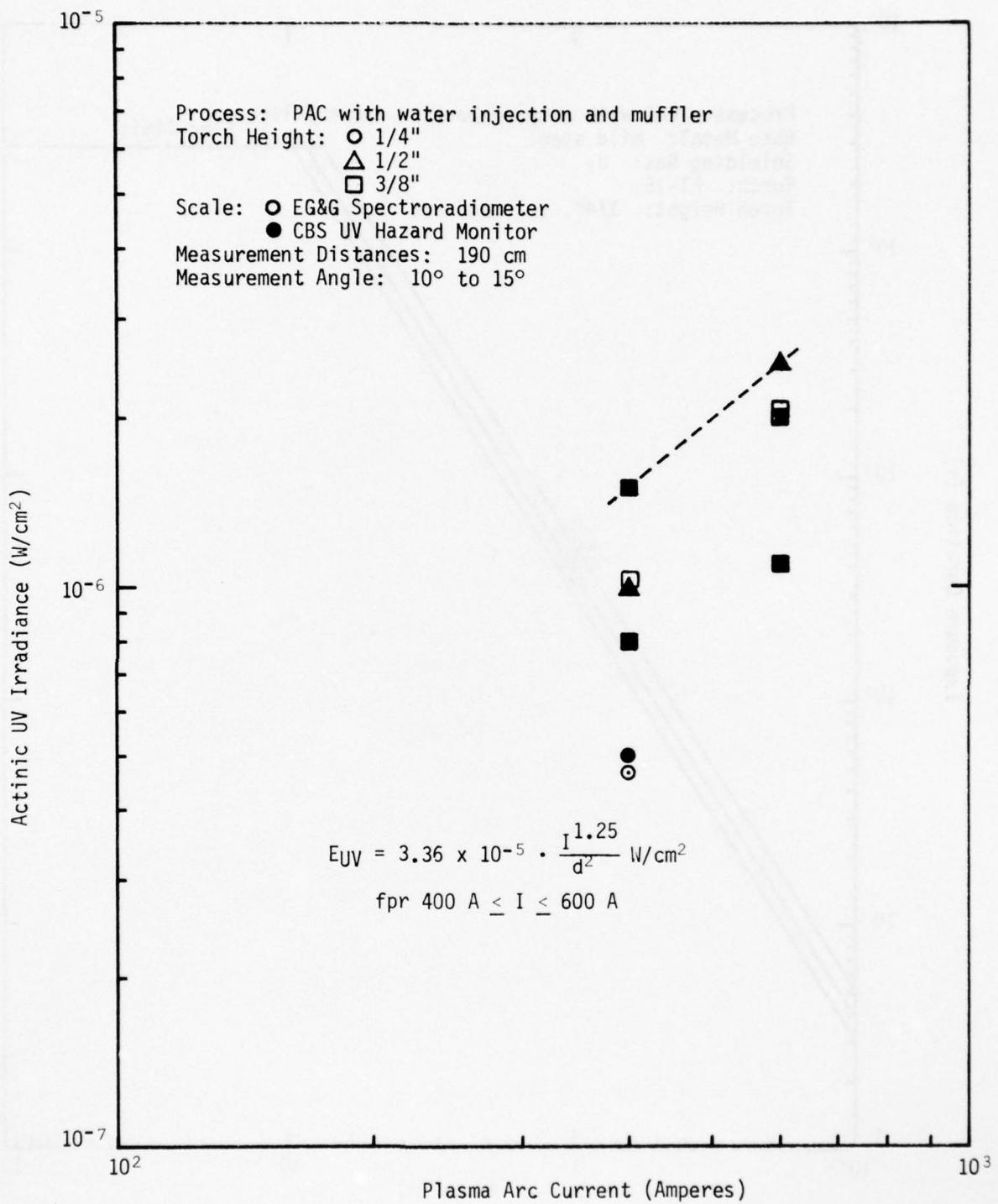


Figure 44. Effective ACGIH Actinic UV Irradiance Versus Plasma Arc Current for Events 82 to 86.

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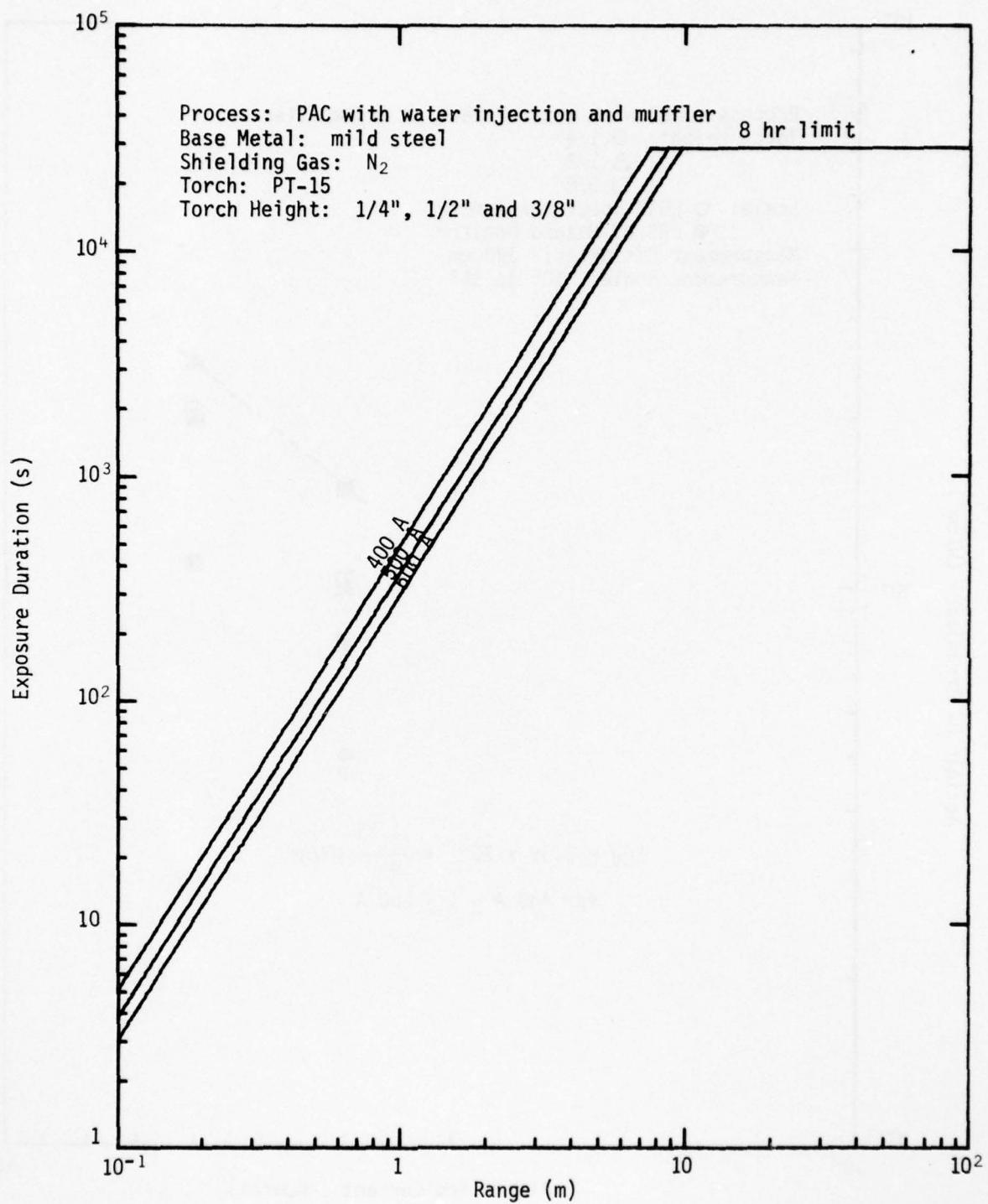


Figure 45. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Plasma Arc Operating at Various Currents for Events 82 to 86.

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TABLE 15. WELDING PARAMETERS FOR EVENTS 87 TO 96.

Process: PAW melt-in and keyhole modes

Mode: Events 87 to 89 were melt-in mode and 90 to 96 were keyhole mode

Base Metal: mild steel

Electrode: 304 s 2% Th (keyhole mode) and 111 M (melt-in mode)

Current Range: 100 to 275 A

Polarity: DCSP

Shielding Gases: Ar, 15% H and 85% Ar, and He

Arc Length: 3/16"

Electrode Diameter: 1/8"

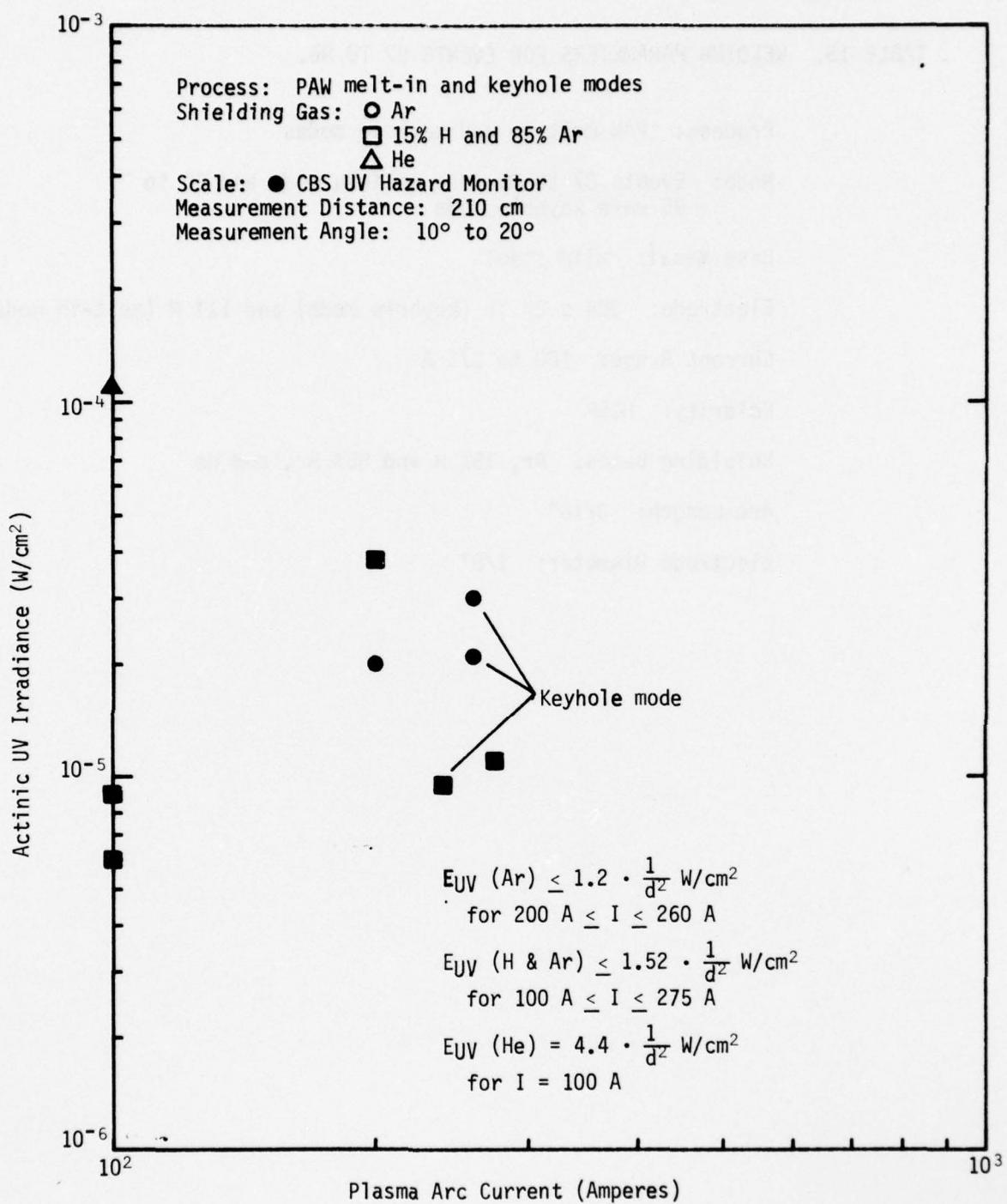


Figure 46. Effective ACGIH Actinic UV Irradiance Versus Plasma Arc Current for Events 87 to 96. The irradiance did not vary significantly between the melt-in and keyhole modes.

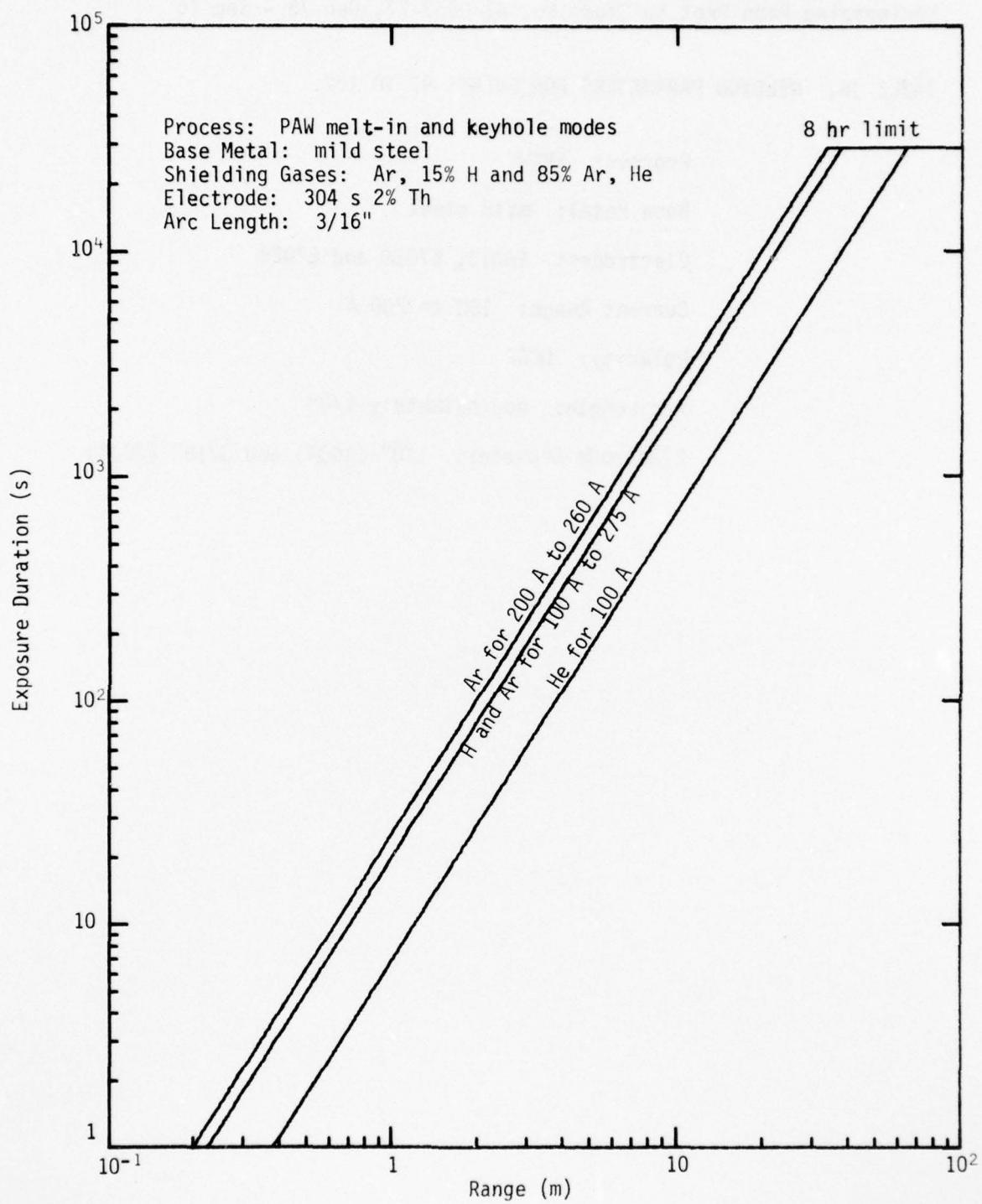


Figure 47. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Plasma Arc Operating at Various Currents for Events 87 to 96.

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TABLE 16. WELDING PARAMETERS FOR EVENTS 97 TO 102.

Process: SMAW

Base Metal: mild steel

Electrodes: E6013, E7018 and E7024

Current Range: 100 to 200 A

Polarity: DCRP

Arc Length: approximately 1/8"

Electrode Diameter: 1/8" (100A) and 3/16" (200A)

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Arc Current: 100A

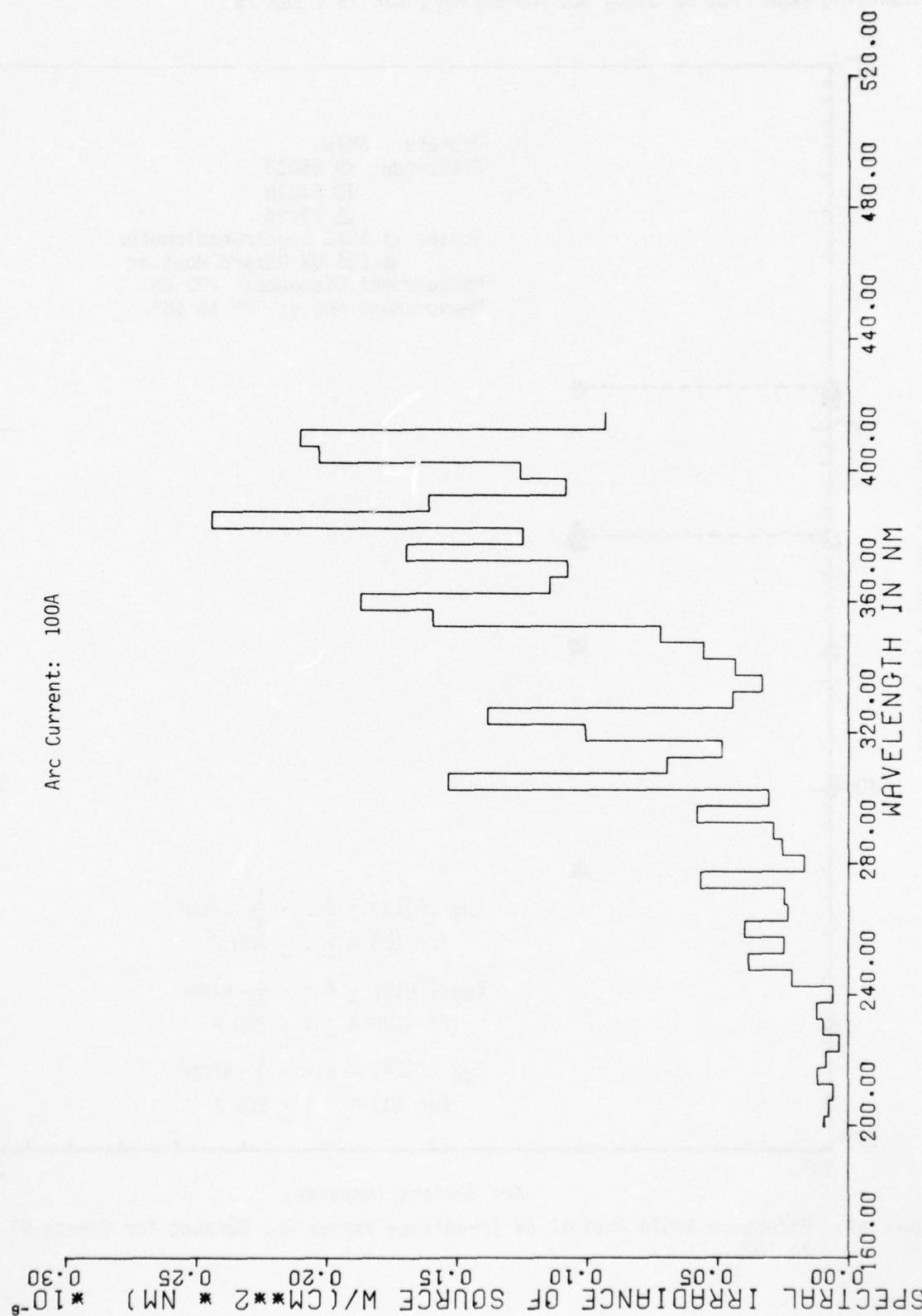


FIGURE 48 . ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 99

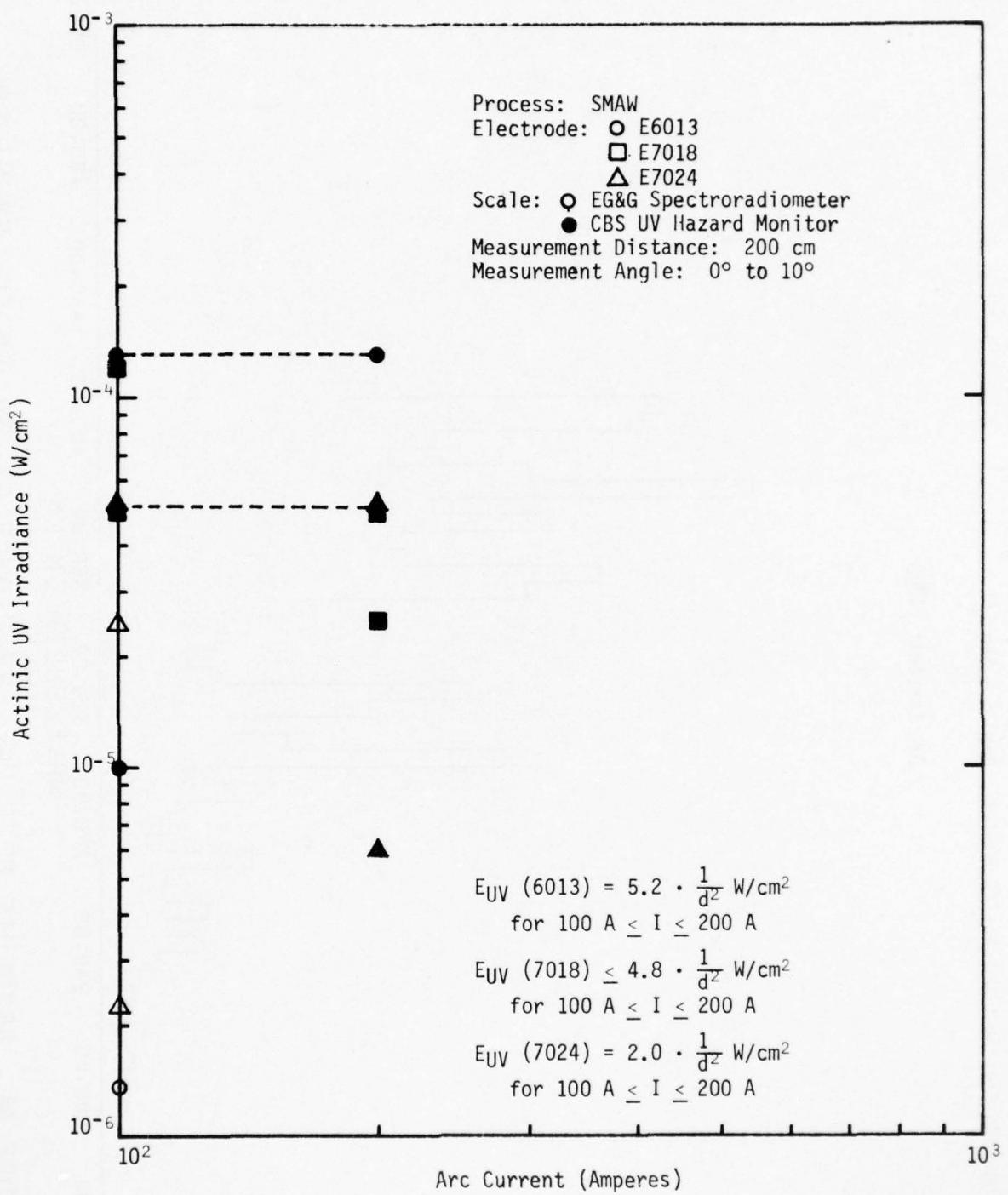


Figure 49. Effective ACGIH Actinic UV Irradiance Versus Arc Current for Events 97 to 102.

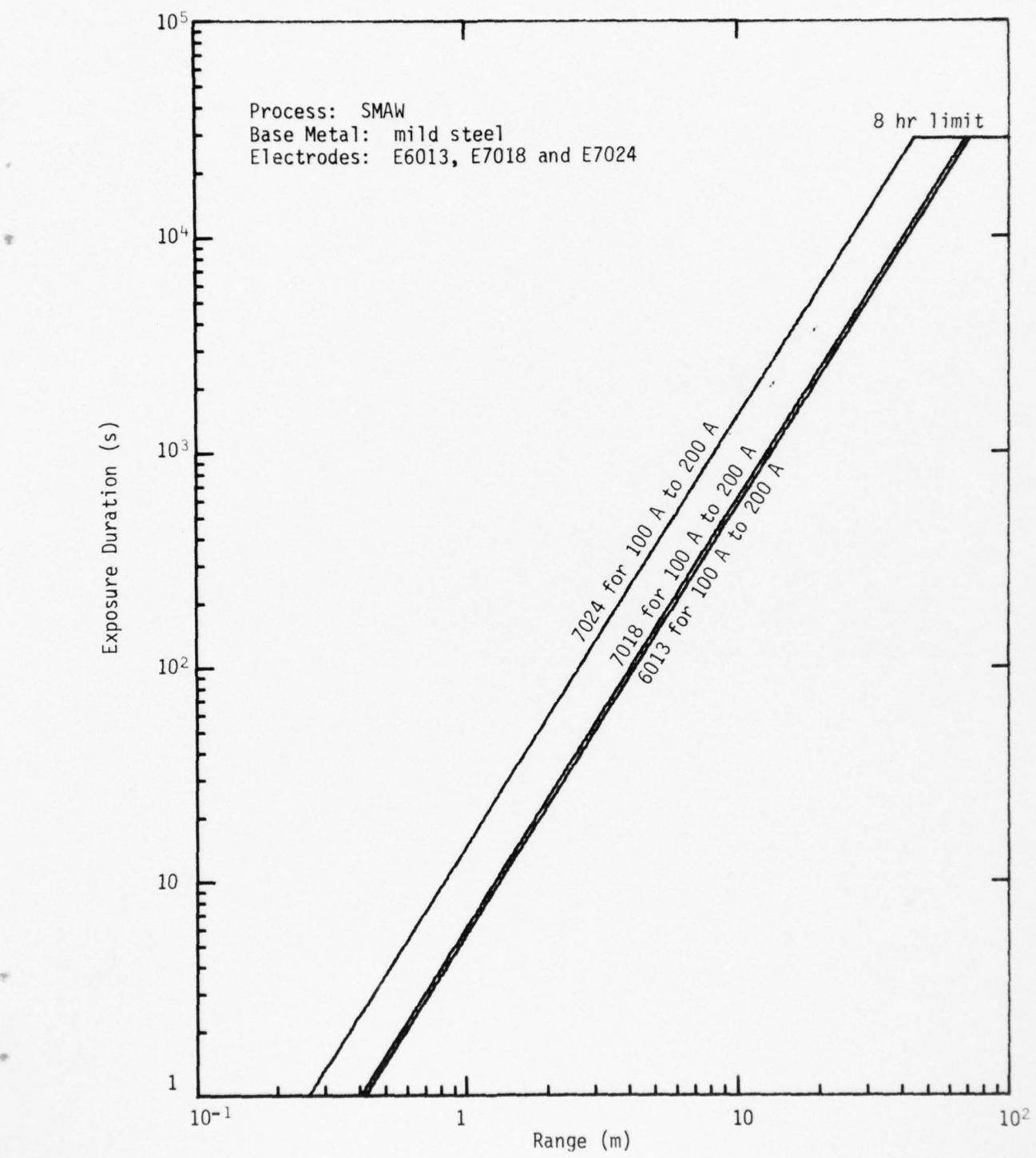


Figure 50. Maximum Permissible UV Exposure Duration for Skin and Cornea Versus Distance from the Welding Arc Operating at Various Arc Currents for Events 97 to 102.

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